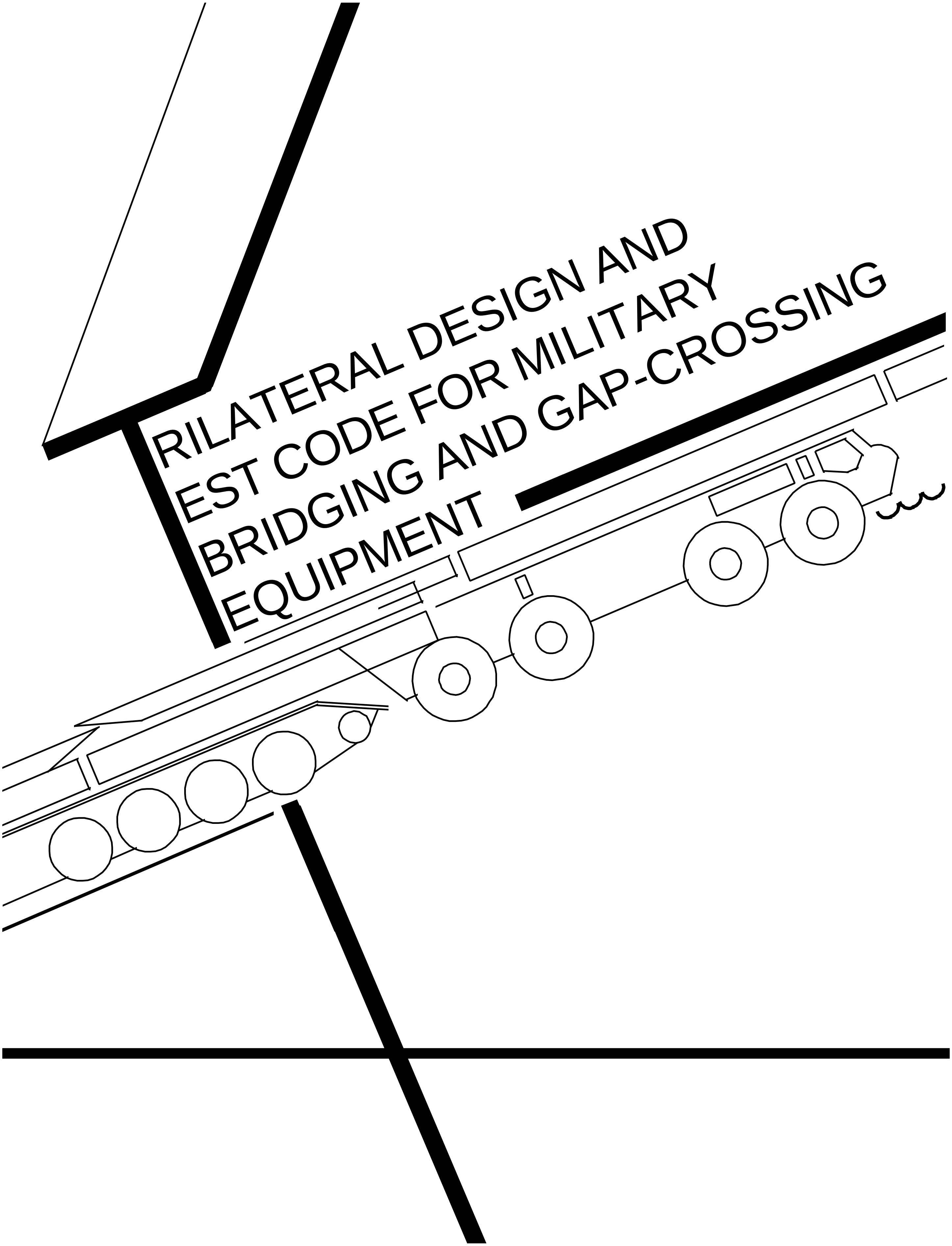
TRILATERAL DESIGN AND TEST CODE FOR MILITARY BRIDGING AND GAP-CROSSING EQUIPMENT



TRILATERAL DESIGN AND TEST CODE FOR MILITARY BRIDGING AND GAP-CROSSING EQUIPMENT

AGREED TO BY:

FEDERAL REPUBLIC OF GERMANY
UNITED KINGDOM
UNITED STATES OF AMERICA

PUBLISHED IN THE UNITED STATES

JANUARY 1996

THIS PAGE INTENTIONALLY LEFT BLANK

Design and Analysis Group National Representatives

Mr. Dieter Rosenthal Bundesamt für Wehrtechnik und Beschaffung-KG IV 2 Postfach 7360 56057 Koblenz Federal Republic of Germany	Telephone: 0-11-49-261-400-6320 Fax: 0-11-49-261-400-6340
Dr. Richard Connor Defense Research Agency Christchurch Bldg. 138 LSF 3b Chobham Lane Chertsey Surrey, England KT16 OEE	Telephone: 0-11-441-344-633044 Fax: 0-11-441-344-633099
Mr. John C. Peterson US Army Tank-Automotive & Armaments Command ATTN: AMSTA-TR-R (MS-21) Warren, MI 48397-5000 United States of America	Telephone: 0-11-01-810-574-6411 Fax: 0-11-01-810-574-8667 E-mail: petersja@cc.tacom.army.mil

THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

1

CONTENTS (Continued)

APPENDIXES (Continued)

FOREWORD

This Code has been agreed to by the Federal Republic of Germany (FRG), the United Kingdom (UK), and the United States of America (US). The Code was prepared by the Design and Analysis Group for Military Bridging and Gap-Crossing Equipment. It was first published in 1974, and in 1984 it also became Quadripartite Advisory Publication 21.

The following systems of units are used:

SI	(ISO 1000, US ASTM E380, and UK PD 5686)
CGS	(FRG DIN)
US Customary	(US NBS Misc. Pub 233)

In order to keep this Code up to date or to modify the requirements when justified by research, test results, or mutually agreed user requirements, it is essential that required modifications and revisions are submitted to the cognizant representatives of the Federal Republic of Germany, the United Kingdom, and the United States of America for agreement. This code has been prepared for the design of bridges and is not intended for vehicle design.

THIS PAGE INTENTIONALLY LEFT BLANK

I. GENERAL

1.1 Introduction.

1.1.1 Bridging and gap-crossing equipment will be designed to meet the user's requirement by applying the necessary loading conditions, design parameters, and testing given in this Code. The Code lists material properties required and gives basic properties for materials generally used. The Code also gives design data for guidance and checking, but the criteria are that the equipment pass the requisite tests, meet the user's requirement, and can be manufactured readily.

1.1.2 Equipment designed and tested in one country in accordance with this Code will be suitable for international acceptance, apart from user or troop trials.

1.2 Scope and Field of Application.

1.2.1 This Code covers loading, design, and testing requirements to be used for the development of military clear-span bridges, piers, floating bridges, rafts, equipment causeways, and erecting and launching structures that are part of the equipment. The Code is used to confirm that equipment will meet the performance specified by the user. The requirements of this Code are to be regarded as the minimum acceptable standards of performance. Requirements for fibrous composite materials and adhesives are included but may not be complete.

1.2.2 If different materials, unusual structures or techniques are used to which some portions of this Code are inappropriate, the engineer is responsible for devising suitable but similar alternative provisions including the specifying and justifying of special tests.

1.3 References.

1.3.1 This Code overrides all other national standards (except those listed below) relating to military bridging and gap-crossing equipment unless such standards are specifically called for by the user. The standards listed below as being valid in addition to the Code should not be regarded as being complete. Additional unforeseen standards which may become relevant in the future should be agreed upon trilaterally.

1.3.2 User's Equipment Requirement: Military Technical and Economy Requirement (FRG); General Staff Requirement (UK); and Operational Requirements Document (US).

1.3.3 NATO STANAG 2021, Computation of Bridge, Ferry, Raft and Vehicle Classifications.

1.3.4 QSTAGS and STANAGS for standardization of equipment and details.

1.3.5 International Organization for Standardization (ISO) International Standards.

1.3.6 American Society for Testing Materials (ASTM) or similar national standards.

1.3.7 Production Specifications.

1.3.8 A list of standards related to paragraphs of this Code is given in Appendix J - STANDARDS.

1.3.9 Mil-Handbook-5, METALLIC MATERIALS AND ELEMENTS FOR AEROSPACE VEHICLE STRUCTURES.

II. DEFINITIONS AND SYMBOLS

2.1 Definitions.

2.1.1 Allowable Stress. The maximum stress allowed caused by the design load, *P*. The stress derived from the proof, yield, or ultimate stress divided by the appropriate safety factor.

2.1.2 Applied Loads. The loads applied to a structure in addition to the dead load, *D*, or self-weight.

2.1.3 Availability. A measure of the degree to which an item is in an operable and committable state at the start of a mission when the mission is called for at an unknown (random) time.

2.1.4 Battlefield Day - see Mission Cycle.

2.1.5 Bearing Contact (Hertz) Stress. The compressive stress due to pressure between elastic bodies.

2.1.6 Buckling Stress. The stress due to the critical buckling load causing unstable equilibrium at which a member fails to perform its load-resisting function due to excessive deflection.

2.1.7 Design Load (*P*). The appropriate combination of loads which must be sustained by a structure without producing stresses in excess of the allowable/working value. For static test purposes it is the Working Load, *P*. In the case of the ductile materials, not sensitive to stress concentrations, average stresses on net sections are satisfactory.

2.1.8 Failure. Failure is when any structural or functional damage causes a member or structure to no longer perform as intended and prevents the completion of its mission; either launching, trafficking, or recovery.

2.1.9 Fatigue Design Life. The required life multiplied by a factor which varies according to the type of design adopted and a further factor if a mean stress/number of cycles (S/N) is used instead of the minimum curve.

2.1.10 Fatigue Stress Range. The stress range to cause failure at the fatigue design life.

2.1.11 Impact Factor. The factor applied to an induced static load to give the equivalent induced dynamic load caused by the load's movement.

2.1.12 Maintainability. The ability of an item, under stated conditions of use, to be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill levels and using prescribed procedures and resources.

2.1.13 Minimum Life. The life at a selected stress from an appropriate S/N curve at 97.5% probability of survival.

2.1.14 Mission Cycle. Includes road march, launch/erection of the equipment, vehicle trafficking and equipment use, and retrieval/disassembly of the equipment.

2.1.15 Pin Bearing Stress. The compression stress normal to the axis of the fasteners (e.g., rivets, bolts, screws) on the projected area of the hole.

2.1.16 Proof Stress. The stress at which a material deviates from the proportionality of stress to strain by a 0.2% strain offset.

2.1.17 Reliability. The probability that an item will perform to its intended function for a specified interval (mission) under stated conditions.

2.1.18 Required Life. The fatigue life stated in the user's requirements.

2.1.19 Rupture Stress. The same as ultimate stress.

2.1.20 Shear Stress. The stress component tangential to the plane in which the forces act.

2.1.21 Slope. Vertical rise or fall over the horizontal distance, usually expressed as a ratio (1 in 10).

2.1.22 Span. The design span is the distance between the reaction point of the bank seats at each support of the bridge. The clear span is the gap to be bridged. See Figure 2.1.

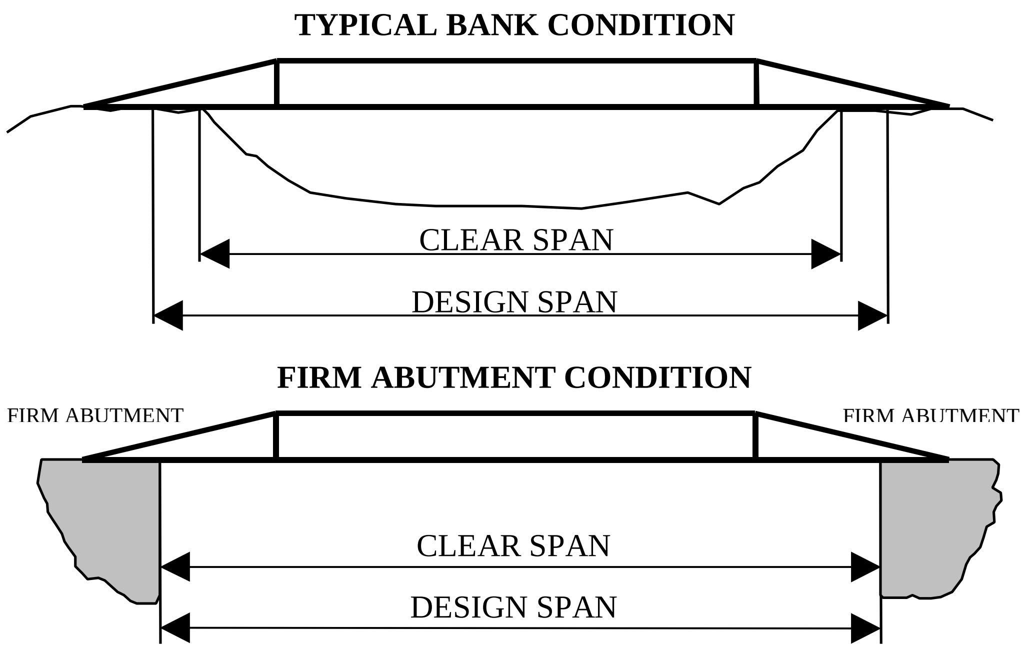


FIGURE 2-1

2.1.23 Stress Ratio. Stress ratio is defined as equal to the minimum stress divided by the maximum stress.

2.1.24 Test Overload (*O*). The design or working load, *P*, multiplied by the factor 1.33.

2.1.25 Test Ultimate Load (*U*). The maximum test load achieved by the bridge structure or component before sudden failure or instability.

2.1.26 Ultimate Stress. The maximum tensile, compressive, or shear stress a material is capable of sustaining.

2.1.27 Working Load (*P*). The same as design load, *P*.

2.1.28 Working Stress. The stress caused by the working load, *P*. The working stress may not exceed the allowable stress.

2.1.29 Yield Stress. The stress at which a material deviates from the proportionality of stress to strain. This deviation may be expressed as a 0.2% strain offset.

2.2 Symbols. The following symbols are used in this Code:

A_i - Applied load to structure or component numbered in order of severity, with A_1 being the most severe.

B - Braking load from vehicle(s).

D - Self-weight or dead load including impact during launching.

F - Footwalk loading.

K_C - Fracture toughness property for material (under plane stress).

K_{IC} - Critical stress intensity for cracking (under plane strain).

K_{th} - Threshold Stress intensity

M - Mud load.

N - Number of cycles to failure.

O - Overload

P - Design load or Working load.

P_C - Stability design load of floating bridge or raft components.

P_{FAT} - Fatigue design load range.

P_{TEST} - Applied test load related to actual material properties.

Q - Hydrodynamic load: the resultant of horizontal drag or propulsion and vertical drawdown components.

R - Function of.

S - Snow or ice load.

T_1, etc. - Strength parameters determined by test.

U - Ultimate load.

U_C - Calculated ultimate load.

U_s - Minimum in-plane shear strength.

V - Vehicle load, including appropriate impact and eccentricity.

W - Wind load at appropriate velocity.

W_P - Wind pressure at appropriate velocity.

X_C - Minimum compressive failure strength of the unidirectional layer parallel to fiber direction.

X_T - Minimum tensile failure strength of the unidirectional layer parallel to fiber direction.

Y_C - Minimum compressive failure strength of the unidirectional layer perpendicular to fiber direction.

Y_T - Minimum tensile failure strength of the unidirectional layer perpendicular to fiber direction.

f_1 - Normal stress in fiber direction.

f_2 - Normal stress perpendicular to the fiber in the plane of the lamina.

f_3 - In-plane shear stress.

f_s - Shear stress.

f_t - Tensile stress.

f_v - Maximum stress.

f_x - Stress in x direction.

f_y - Stress in y direction.

h - Height difference between near and far banks.

n - Required number of cycles/life.

p_b - Tracked vehicle ground contact bearing pressure on hard surface.

v - Velocity.

σ - Standard deviation.

Additional symbols are defined in applicable appendixes.

2.3 Conversion Factors. Conversion factors for SI, Metric, and English units are in Appendix B - CONVERSION FACTORS.

THIS PAGE INTENTIONALLY LEFT BLANK

III. MATERIALS

3.1 General. This section gives the material data which should be available to the designer and is required for international standardization. The data should be presented in the form used in Appendixes A - METAL DATA SHEETS, E - COMPOSITE MATERIALS DATA FORM, and F - ADHESIVE DATA FORM.

3.2 Material Listing. Appendix A - METAL DATA SHEETS, is a list of metals with brief information to assist initial selection. These are not the only metals for consideration. Approximate properties for composites for preferred methods of fabrication are given in Appendix G - TYPICAL BASIC PROPERTIES OF FIBER-REINFORCED MATERIALS BASED ON 60% FIBER VOLUME FRACTION EPOXY COMPOSITES.

3.3 Preliminary Working Stresses. If when a metal is first considered only the 0.2% proof for yield strength is known, the following factors may be used to obtain other working stresses from the working tensile stress:

Compression without buckling = tension.
Shear = 0.6 x tension.
Bearing = 1.33 x tension.

3.4 Data required for Selected Materials.

3.4.1 General. Name and/or number of material with a brief statement of the primary characteristics and any patent or proprietary restrictions.

3.4.2 Application. State what the material is used for and the particular properties that make it desirable.

3.4.3 Physical Properties. Give density, melting range, and average coefficient of thermal expansion for -18 to 65 °C (0 to 150 °F).

3.4.4 Elastic Constants. Give at 20 °C (68 °F) the Modulus of Elasticity, in tension and compression, and Poisson's ratio. Orthotropic properties should be given to consider the effect of grain orientation. Variances of more than 5% at 38 °C (100 °F) should be noted.

3.4.5 Fabrication Recommendations. List any special recommendations for working with the material.

3.4.6 Ballistic Damage. It should be shown that any material or construction is satisfactory with respect to ballistic damage. An assessment may be made on the basis of impact tests, fracture toughness, notch tensile/compression tests, drop tests, and field shooting trials followed by test loading.

3.5 Data Required for Selected Metals.

3.5.1 Physical Condition Designation. List and define all common heat-treatment designations.

3.5.2 Chemical Composition. Give the maximum and minimum allowable percentage by weight of alloying elements and the maximum allowable percentage by weight of contaminating elements.

3.5.3 Mechanical Properties. Minimum properties will be given for the parent metal and, if they are different, for welds, Heat Affected Zones (HAZ), and, if applicable, for differently worked forms. Parent-metal properties will be given for the longitudinal direction, in the rolling or extrusion direction, and, if they differ, for the long-transverse and short-transverse directions as well as for various thicknesses. In general, ultimate strength, yield strength, and elongation are guaranteed; however, other mechanical properties must be established and are minimum properties which can be expected but are not guaranteed.

3.5.3.1 Tensile. Give the 0.2% proof strength, or yield strength, for a 0.2% offset and the ultimate strength. Give percent elongation in the longitudinal (rolling or extruding) direction with a 50 mm (1.97 in) gage length. Testing should be in accordance with ISO/R82, R86, and R375; EN 10002 PT 5*; ASTM E8; BS 18.

3.5.3.2 Compression. Give the 0.2% proof strength, or yield strength, and the ultimate strength. Testing should be in accordance with ASTM E9.

3.5.3.3 Bearing. Give the 2% offset bearing strength. Testing for pin bearing should be in accordance with ASTM E238.

3.5.3.4 Shear. Give the shear strength. Testing should be in accordance with ASTM B565.

3.5.4 Fatigue Properties. Desirably give minimum stress/number of cycles (S/N) curves between 10^3 and 10^6 cycles with a 97.5% probability of survival on a log-normal distribution for stress ratios 0, +0.5, -1 for the following specimens as required.

Smooth-base material.
Notched-base material.
Butt welds.
Fillet welds.
Connections other than welds.

3.5.5 Fracture Data. Compare with other alloys and give the parameters K_C and K_{IC} with details of the test specimen. Testing for K_{IC} should be to ASTM E399. Threshold stress intensity

* DIN 50-145 withdrawn in 1991, replaced by EN 10002 PT 5.

K_{th} and crack propagation data based on the fracture mechanics should be available for base material and welds/HAZ's.

3.5.6 Corrosion Resistance. Briefly compare corrosion resistance with that of other alloys of the same material. Special corrosion characteristics including the effects of heat treatment, welding, and aging should be mentioned if they differ greatly from similar alloys.

3.5.7 Stress Corrosion. Briefly compare with other similar alloys. Give the threshold stress below which stress-corrosion cracks do not initiate for smooth specimens, preferably in four-point bending, stating the time, environment, material, grain structure, and specimen orientation.

3.5.8 Heat Treatment. Give details of any heat-treatment processes pertaining to the material. Appendix D - INTERNATIONAL TEMPER EQUIVALENTS FOR ALUMINUM ALLOYS, summarizes heat treatment equivalents for the three member countries.

3.5.9 Welding and Joining. Give recommended welding electrodes and any special joint-preparation requirements.

3.5.10 Brittle Fracture. It should be shown that the material, as used in the structure, will not be subject to brittle fracture at the required low temperature by quoting nationally accepted tests or the transition temperature if applicable.

3.6 Data Required for Selected Composites.

3.6.1 General. This section includes glass, aramid, and carbon composites. It considers only the properties of the most commonly used cured composite for preferred methods of manufacture and adhesives. Individual properties of fibers and resin matrix should be entered on the Data Sheet shown in Appendix E - COMPOSITE MATERIALS DATA FORM, if available. Although these properties determine composite characteristics, they are no more than a guide to the expected composite material property levels. Physical and mechanical property data should be measured at 23 ± 2 °C (73 ± 4 °F) and 50 ± 5% relative humidity (RH). Mechanical property data should also be measured at temperature and humidity conditions representative of severe operation, 50 ± 2 °C (122 ± 4 °F) and 85 ± 5% RH, or a higher or lower* condition, if specified. Preconditioning is required to achieve the equilibrium humidity content and temperature consistent with the test temperature and moisture (see ASTM D618 on preconditioning).

3.6.2 Composite Description. Sufficient detail should be specified to define the composite constituents uniquely either in terms of manufacturers' coding or to accepted specifications. Layup geometry, number of plies, volume fraction, and final thickness of the composite should be given.

* STANAG 2831 withdrawn.

3.6.3 Processing. The method of producing the cured composite form should be stated with details of curing times, pressures, and temperature cycles.

3.6.4 Physical Properties.

3.6.4.1 The density, fiber volume fraction, and void content should be stated and determined in accordance with appropriate published standards. Calibrated alternative methods are accepted.

3.6.4.2 Thermal expansion coefficient related to the operating temperature range should be given.

3.6.4.3 Equilibrium moisture content and relative linear dimensional changes should be determined for the most severe operating conditions (temperature and humidity). This information should be used to specify preconditioning for test specimens. The glass transition temperature for the composite should also be given.

3.6.5 Basic Lamina Mechanical Properties. The level of mechanical properties depends upon the strain rate and the physical state of the material in respect to temperature and moisture content. Properties for design should include measurement at the minimum median and maximum operating temperatures and show changes associated with moisture pick up. Preconditioning test conditions should be as specified in paragraph 3.6.1. Property data should be provided for individual lamina and for the (laminated) composite. The required lamina properties are identified in Appendix E - COMPOSITE MATERIALS DATA FORM, and include tensile and compressive strength parallel and orthogonal to the fiber direction and inplane shear strength (see ASTM D3039, D3410, and D3518). Minimum guaranteed fiber strain must also be reported. Interlaminar shear strength (or transverse shear strengths for other than laminated composites) should be measured by a procedure to be agreed upon.

In addition, longitudinal, transverse, and shear moduli and Poisson's ratios should be obtained for the individual lamina. Longitudinal tensile, compression, flexural strength and Poisson's ratios should be obtained on full thickness (laminated) composite coupons with the stacking sequence to be utilized in production at severe operating conditions only as specified in paragraph 3.6.1. Geometric discontinuities should be considered.

The mean value and standard deviation of each property should be determined from a minimum sample size of 6.

Application of any failure criteria to establish a composite strength analysis for a multiaxial laminate in either a uniaxial or multiaxial stress state requires a coherent set of basic ply properties as given in Appendix E - COMPOSITE MATERIALS DATA FORM. Test methods to be based on appropriate published standards.

3.6.6 Fatigue Properties. Fatigue properties should be determined by test on appropriate specimens (ASTM D3039 provides specimen information). Test conditions should be designed to avoid heat build-up (ASTM D3479).

A testing program can be performed which provides minimum S/N curves between 10^3 and 10^6 cycles with a 97.5% probability of survival on a log normal distribution for stress ratios of 0, +0.5, -1.

Alternatively, testing can be performed for the most severe operational stress envelope, i.e. between the minimum and maximum transient stress to which the component may be subjected, increased for a number of cycles equal to 1.8 times the design life.

In either case, tests should be performed on full thickness specimens with the design stacking sequence for both smooth specimens and specimens containing geometric discontinuities (holes and/or notches) representative of design items.

Correctly loaded components should be tested.

3.6.7 Impact Susceptibility. Determine threshold of impact induced interlaminar damage by drop weight tests; specification to be agreed upon.

3.6.8 Stress Rupture/Creep. Determine to agreed specifications constant stress versus time curves for selected critical material stress cases. Creep behavior should be investigated at the maximum service temperature. The tensile specimen (ASTM D3039) is appropriate for both creep and stress rupture testing.

3.7 Data Required for Selected Adhesives.

3.7.1 General. This section relates to adhesives for structural composite bonded joints and metal attachments. The performance of adhesives can be significantly influenced by the prior preparation of the surfaces bonded. Guaranteed minimum strength properties must be established by testing representative joints. Typical data requirements are indicated in Appendix F - ADHESIVE DATA FORM. Test conditions (temperature and humidity) and preconditioning should be as specified in paragraph 3.6.1 for composites. Correctly loaded joints should be tested.

3.7.2 Adhesive System Description. Described by giving the manufacturer's coding and supplier and the form of adhesive used (liquid, paste, or film). The nature of the adhesive should be stated giving intended application (adherends and service environments). The system components should be listed including compatible primer systems.

3.7.3 Processing Requirements. Indicate surface preparation, assembly methods, and pressures and time/temperature cycles to obtain stated properties. Minimum curing temperatures should be given and range of allowable bond line thickness stated.

3.7.4 Physical Properties of Cured Adhesive.

3.7.4.1 State the glass transition temperature.

3.7.4.2 State the transverse electrical resistivity.

3.7.5 Mechanical Properties. The level of mechanical properties may be affected by the strain rate of testing and the physical condition of the bonded system. Mechanical property data should be developed at the conditions defined in paragraph 3.6.1. The following data should be reported: tensile and shear load, and peel strength; tensile and shear moduli, elastic, and inelastic tensile and shear strain limits. Application of the data in Appendix F - ADHESIVE DATA FORM, to selected joint configurations should take into account stress concentrations arising from geometrical factors and adherend stiffness. Test methods should be in accordance with appropriate published standards, such as ASTM E229 (shear strength and modulus), ASTM D897 (tensile strength), ASTM D1876 or D3167 (peel strength).

3.7.6 Fatigue Properties. Fatigue properties of many adhesives are particularly sensitive to cycling rate and should be determined under conditions close to that of use under the most severe operating environment. The following fatigue tests should be performed: tension, shear, and peel. Either minimum S/N to failure curves should be developed or fatigue tests specific to the design load envelope should be carried out as specified in paragraph 3.6.6. Adhesive fatigue properties may be compared using standard test methods but allowance for geometrical stress concentrations should be made on other joint geometries and testing of representative test coupons is essential.

3.7.7 Environmental Degradation. A ranking of the expected durability of selected adhesive/adherend surfaces should be given in terms of wedge test crack propagation or stressed lap shear test, but specific factors can be obtained only by testing representative joint details. Full details of surface preparation techniques should be given. The rate of environmental degradation will also depend on the specific geometry and stress system applied to the bonded joint.

3.7.8 Creep Behavior. To be based on ASTM D2294 or British Standards 3250 Part C7 with preference for a thick adherend single-lap shear specimen. Creep behavior should be investigated at the maximum service temperature.

IV. DESIGN PARAMETERS

4.1 General. The design parameters below are to be used unless modified by the equipment requirement/specification. Generally, the parameters represent the worst conditions achieved during normal service, and average usage should not be so severe. In some instances a desirable alternative parameter is given, and it should be regarded as an improvement that the designer should try to achieve. The designer will have to balance cost and effect with the achievement of desirable parameters, and it may not be possible to achieve all parameters. Abnormal service parameters should be covered by special tests on the equipment. Parameters are given for clear span bridges, piers, floating bridges, and rafts.

4.2 Clear-Span Bridge and General Parameters.

4.2.1 Minimum Clear Roadway Width (STANAG 2021):

Military Load Class (MLC)	One-Way	Two-Lane (Equal MLC)
4-12	2.75 m (9 ft)	5.50 m (18 ft)
13-30	3.35 m (10 ft, 11 in)	5.50 m (18 ft)
31-60	4.00 m (13 ft, 1 in)	7.30 m (24 ft)
61-100	4.50 m (14 ft, 9 in)	8.20 m (27 ft)

4.2.2 Truss Bridge Roadway Width. For through truss bridges with exterior curbs: Face of curb to inside of truss to be 250 mm (10 in) minimum from 300 mm (12 in) above the deck to the top of the truss.

4.2.3 Footwalk Width. Width will be a minimum of 650 mm (2 ft, 2 in).

4.2.4 Trackway width for MLC 31 and above. Minimum width for single trackway will be 1,525 mm (5 ft). Maximum center gap will be 950 mm (3 ft, 1 in). (Dimensions must be checked to suit all vehicles expected to use the trackway.)

4.2.5 Bank Conditions. For assault (close support) bridges, the height difference between home and far banks is desirably 1 in 5 (20%) up to a maximum of 6.0 m.

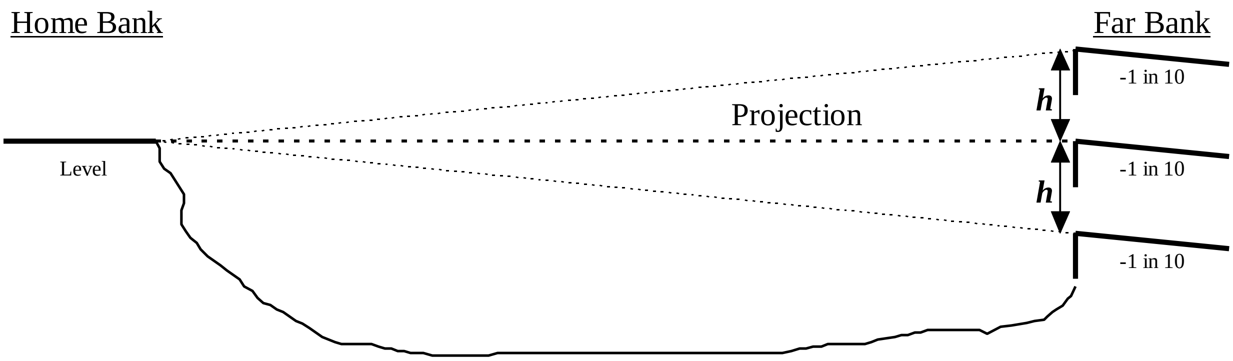
For support (general support) bridges, the maximum height difference, *h*, between home and far banks is related to the projection of the home-bank plane in the following manner: 1/10 multiplied by the length of the span up to a maximum of 3.0 m (9 ft, 10 in). See Figure 4.1.

The home and far banks may have the following slopes and these slopes may be combined with the height difference between the home and far shore banks.

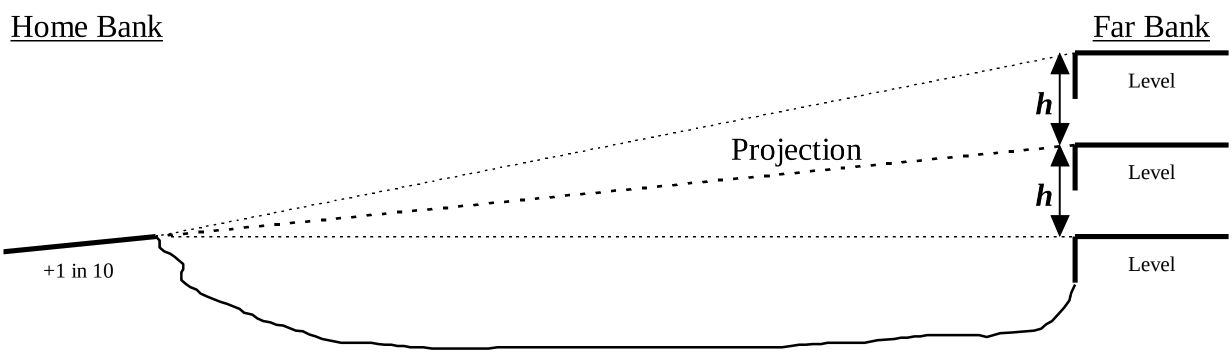
Transverse slopes including irregularities +1 in 20, one end; ±1 in 20, other end.

BANK CONDITION
HEIGHT DIFFERENCES

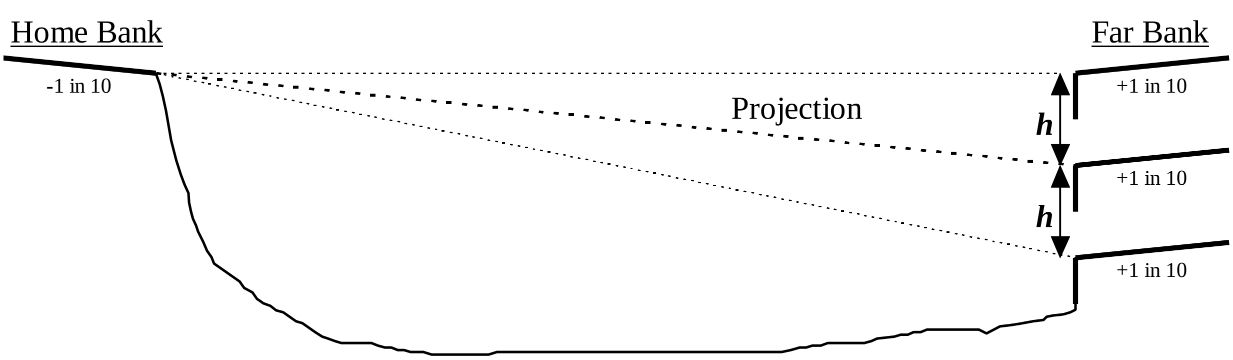
Home and Far Bank height difference, *h*, over the span range 0-30 m (0-98 ft) is given by: *h* ≤ 1 in 10 of the span as shown in the figures below. Spans greater than 30 m (98 ft), *h* = 3 m (9 ft, 10 in).



For illustrative purposes the Home Bank slope is shown level (May be ±1 in 10) and the Far Bank slope is shown at -1 in 10 from horizontal (May be ±1 in 10).



For illustrative purposes the Home Bank slope is shown at +1 in 10 from horizontal (May be ±1 in 10) and the Far Bank slope is shown level (May be ±1 in 10).



For illustrative purposes the Home Bank slope is shown at -1 in 10 from horizontal (May be ±1 in 10) and the Far Bank slope is shown at +1 in 10 from horizontal (May be ±1 in 10)

FIGURE 4-1

Longitudinal slope on building or recovery site to be considered with transverse slopes: ±1 in 10, including irregularities.

Bankseat-, launching-, or recovery-area irregularities are steps, bumps, or depressions anywhere on the width covered by the bridge (see paragraph 4.2.1 for minimum widths) or area spanned by the launching system. The bridge must be designed to handle a height or depth irregularity of ±150 mm (6 in) minimum and desirably ±300 mm (12 in).

4.2.6 Bank Bearing Pressure. The effect of bearing on hard, high spots should be considered. The bridge should be usable on softer banks down to 110 kN/m^2 (11,220 kp/m^2, 1.0 ton/ft^2) when sinkage will assist by increasing bearing area and/or pressure. It is accepted that banks with a bearing pressure less than 110 kN/m^2 (11,220 kp/m^2, 1.0 ton/ft^2) may require additional grillage and/or trackway.

It may be considered that at a minimum the bridge shall be capable of resisting the complete reaction/bearing load on a 1.0 m (3 ft, 3 in) length of bridge, desirably 0.5 m (1 ft, 8 in), anywhere a bearing can occur.

A minimum bearing area acceptable at the ramp tip will allow for the complete design span on banks of down to 200 kN/m^2 (20,400 kp/m^2, 2.1 tons/ft^2) ground bearing capacity.

4.2.7 Depth of Bridge at Ramp Toe:

Condition	Assault (Close Support) Bridge	Support (General Support) Bridge
Maximum	100 mm	75 mm
Desirable	50 mm or less	Minimum possible

4.2.8 Bridge Deck Slopes. The allowable longitudinal slopes for a bridge with level supports and no applied loads, A_i, are given in the following table. The transverse slope allowing for the support conditions of paragraph 4.2.5 and the unfactored fully eccentric vehicle load, V, with impact should not exceed 1 in 10.

Description	Assault (Close Support) Bridge	Support (General Support) Bridge
Short ramp or sloping end of bridge up to 3 m (9 ft 10 in) long:		
Maximum	1 in 5	1 in 7
Desirable	1 in 7 or less	1 in 10 or less
Ramp or sloping end of bridge longer than 3 m (9 ft 10 in):		
Maximum	1 in 6	1 in 9
Desirable	1 in 10 or less	1 in 14 or less
Change of slope on bridge other than at sloping ends:		
Maximum	1 in 6	1 in 10
Desirable	1 in 10 or less	1 in 20 or less

4.2.9 Wind Velocity and Pressure. The wind velocities and pressures are the maximum values to which the bridge should be designed:

Design Condition	Wind Velocity (v) m/s	(knots)	Wind Pressure (W_P) kN/m^2	(kp/m^2)	(lbf/ft^2)
During construction /launching	15	29.2	0.138	14.1	2.88
On bridge and crossing vehicle	20	38.8	0.245	25.0	5.11
On bridge alone	30	58.3	0.552	56.2	11.51

4.2.10 Vehicle Design Crossing Speed. Essential speeds are the maximum speeds under normal field conditions and the speeds up to which bridges must be tested:

Vehicle Design Speed	Up to MLC 30	Above MLC 30
Essential	25 km/h (15 mi/h)	16 km/h (10 mi/h)
Desirable	40 km/h (25 mi/h)	25 km/h (15 mi/h)

4.2.11 Impact. For clear-span bridges, vehicle induced loads will be increased by the following factors to cover crossing speeds up to 25 km/h (15 mi/h):

Location	Impact Factors: Bending Moment and Deflection	Shear Force
Interior	1.15	--
Ramp	1.2	1.2

It should be noted that these values cover modern suspension vehicles for the desirable velocity and old suspension and high pitch inertia vehicles for the essential velocity according to paragraph 4.2.10. The given factors are typical values so that for extreme cases a more detailed investigation for design is recommended. An increase of 15% for impact will be added to the bridge dead load, *D*, and launching equipment if appropriate during launching.

The maximum included static load multiplied by the impact factor results in the maximum induced dynamic load.

4.2.12 Mud Load (*M*). The following load will be used when calculating the effects of mud on the roadway surface: 0.75 kN/m^2 (76 kp/m^2, 15.67 lbf/ft^2)

4.2.13 Snow and Ice Load (*S*). The following load will be used if it has a greater effect than the mud load, *M* (300 mm (12 in) of loose snow of areal density): 370 N/m^2 (37,740 kp/m^2, 7.7 lb/ft^2).

4.2.14 Footwalk Loading (*F*). The footwalk should sustain a maximum load of 3.83 kN/m^2 (390 kp/m^2, 80 lbf/ft^2). For spans in excess of 33.3 m (109 ft, 3 in), the total load effect is considered as that caused by a load of 1.92 kN/m^2 (196 kp/m^2, 40 lbf/ft^2). An individual soldier is taken as a load of 0.89 kN (91 kp, 200 lbs).

4.3 Piers.

4.3.1 Dimensions. The following values are to be used for pier design:

Measurements	Assault (Close Support) Bridge (Two Span)	Support (General Support) Bridge (Two or More Span)
Height, River Bed to Deck:		
Minimum	4 m (13 ft, 1 in)	7 m (23 ft)
Desirable	5 m (16 ft, 5 in)	12 m (39 ft, 4 in)
Water Depth:		
Minimum	3 m (9 ft, 10 in)	6 m (19 ft, 8 in)
Desirable	4 m (13 ft, 1 in)	

4.3.2 Grillage Bearing Pressure. Maximum: 160 kN/m^2 (16,320 kp/m^2, 1.7 ton/ft^2). (Some sinkage allowed.)

4.3.3 Current Speeds. The current speeds for piers are the same as those given for floating bridges and rafts (paragraphs 4.4.1).

4.3.4 Pier Support. These should articulate in any direction to allow a longitudinal and transverse bridge slope of at least ±1 in 10 under live vehicle loading.

4.4 Floating Bridges and Rafts.

4.4.1 Current Speeds:

Condition	Speed
Construction and normal use:	2.5 m/s (4.9 knots)
Unladen equipment survival:	
Minimum:	3.5 m/s (6.8 knots)
Desirable:	5.0 m/s (9.7 knots)

4.4.2 Raft Speed Laden:

Condition	Speed
Minimum:	2.5 m/s (4.9 knots)
Desirable:	3.5 m/s (6.8 knots)

4.4.3 Worst Case Shallow Water, Fast Current Condition: Midstream: 2 m (6 ft, 7 in) of water running at 2.5 m/s (4.9 knots).

4.4.4 Worst Case Shallow Water Condition at Bank for Ramp and Flotation: River bed slopes down 1 in 7 from water's edge.

4.4.5 Bank-Height/Ramp-Elevation Ranges:

Condition	**Range**
Upward:	
Minimum	+1.5 m (4 ft, 11 in)
Desirable	+2.0 m (6 ft, 7 in) (Relative to water level.)
Downward:	Bottom of ramp toe should be level with bottom of main floating structure.

The ramp slopes on rafts and bridges should not exceed the values given in paragraph 4.2.8 for the worst condition of loading.

If these bank heights are used for launching floating equipment, it is not realistic to combine them with the worst shallow water depth in paragraph 4.4.4. A water depth of 2.0 m (6 ft, 7 in) can be assumed 8.0 m (26 ft, 3 in) from the water's edge.

4.4.6 Pontoon Bottom-Skin Load. The pontoon bottom-skin load should not exceed 96 kN/m^2 (9800 kp/m^2, 2,005 lbf/ft^2).

4.4.7 Minimum Freeboard. The following minimum freeboard values with the maximum MLC vehicle load(s) fully eccentric are considered adequate for normal equipment configurations at the design current speed. See paragraph 4.4.1.

	Minimum Freeboard of Pontoon			
	Bow		**Side**	
Floating Support	**mm**	**(in)**	**mm**	**(in)**
Pneumatic Floats	100	(4)	0	(0)
Rigid Open Pontoons	225	(9)	125	(5)
Rigid Closed Pontoons	150	(6)	100	(0)
Rigid, Continuous Closed Pontoons	50	(2)	0	(0)

4.4.8 Trim. A floating bridge or raft with a vehicle at permitted eccentricity should not trim so that the deck slope is more than 1 in 20 under the worst permitted hydrodynamic conditions.

4.5 Typical Vehicle Data for Design.

	MLC	Center of Gravity (CG) Maximum Height m	(in)	Side Wind Area m^2	(ft^2)	Center of Pressure Height m	(in)
Wheeled	10	2.030	(80.00)	16.20	(174.50)	1.830	(72.00)
	16	2.280	(89.76)	18.00	(193.75)	1.900	(74.80)
	25	2.097	(82.56)	23.17	(249.40)	1.916	(75.40)
	30	2.670	(105.1)	30.00	(322.90)	1.910	(75.20)
	90/100	2.100	(82.70)	42.69	(459.00)	1.730	(68.00)
Tracked	8	0.846	(33.30)	06.56	(070.50)	1.020	(40.00)
	16	0.915	(36.00)	11.42	(123.00)	1.158	(45.60)
	30	1.113	(43.80)	12.38	(133.00)	1.290	(51.00)
	60	1.245	(49.00)	16.72	(180.00)	0.915	(36.00)
	70	1.250	(49.20)	16.74	(180.19)	1.250	(49.20)

4.6 Temperature and Environment. The environmental effects due to the required categories must be considered*. Thermal stresses and long-term degradation due to temperature and humidity must be considered.

* STANAG 2831 withdrawn.

THIS PAGE INTENTIONALLY LEFT BLANK

V. LOADS AND LOAD COMBINATIONS

5.1 General. The designer will use the most critical loading obtained from paragraph 5.3, Military Bridge Loads, using the values given here or detailed in Section IV, DESIGN PARAMETERS and the combinations given in paragraph 5.4, Load Combinations. The worst support conditions must also be taken into account.

5.2 Deflections. Deflections are not limited directly by this code but must be considered when they cause changes in loading, affect fit or alignment, or affect the use of equipment.

5.3 Military Bridge Loads.

5.3.1 Dead Load (*D*). The structure dead load, *D*, shall consist of the weight of the complete bridge for the structure in place or of the appropriate bridge components.

5.3.2 Vehicle Load (*V*).

5.3.2.1 The vehicle load, *V*, is represented by the hypothetical vehicle of the required load class depicted in STANAG 2021 (see Appendix C - HYPOTHETICAL VEHICLES FOR MILITARY LOAD CLASSES). The most critical loads induced by any of the following with the impact factor will be used:

The hypothetical tracked vehicle.
The hypothetical wheeled vehicle.
The hypothetical axle load.
The hypothetical single-wheeled loads.

If a vehicle other than the hypothetical STANAG vehicle is used, problems will be encountered with variations in load class or the load to give the correct bending moment or shear. These occur due to changes in bridge length and vehicle width.

5.3.2.2 For tracked vehicles, the load will be applied as follows for each track: For Military Load Class (MLC) 30 and above, there will be 6 contact areas and for MLCs lower than 30 there will be 5 contact areas. These represent the road wheels and must be fitted into the hypothetical track length allowing for the contact area length. The width of each contact area is taken as the hypothetical vehicle track width and the contact area length along the track is taken so that the working load bearing pressure:

$$p_{\mathrm{b}} = 0.6 + \frac{\mathrm{MLC}}{100} \ \mathrm{N/mm^2}$$

If the number of contact areas is reduced or increased, p_{b} must be changed accordingly. For wheeled vehicles, the wheel load will be applied on a contact area, with the nominal tire width and load of the hypothetical vehicle (Appendix C - HYPOTHETICAL VEHICLES FOR MILITARY LOAD CLASSES) which will produce a contact pressure of 1.25 times the tire pressure at working load not to exceed 1100 kN/m^2 (112 kp/cm^2, 160 lbf/in^2).

5.3.2.3 Consideration should be given to changes in individual wheel and tank-track bogie loads as vehicles pitch or negotiate changes in slope.

5.3.3 Mud Load (*M*). The mud load, *M*, in the design parameters will be considered over the roadway area. Reductions in loading may be made for proven self-cleaning decks. Accumulations of mud on vehicles will not be considered. It is assumed that mud is removed from bridges before they are recovered or retrieved. If this is not possible, a percentage of the mud load, *M*, should be included in the weights for retrieval purposes. This percentage is a function of the particular bridge design and will range from 10 to 25% of the total. The impact factor should be considered in addition.

5.3.4 Snow and Ice Load (*S*). The snow and ice load, *S*, in the design parameters is applied uniformly over the bridge and flotation plan area. The load, *S*, will not be applied unless the effect is greater than the mud load, *M*, in which case it will be used instead of the mud load, *M*. Accumulation of snow and ice on vehicles will not be considered.

5.3.5 Impact. To provide for impact on clear-span (fixed) bridges, the vehicle induced load, *V*, will be increased as required by the design parameters. The impact factor will be applied to the bridge dead load, *D*, for the bridge launching condition only as required by the design parameters. For floating bridges, the impact factor in the center section will be 1.05 for ramp (landing bay) slope of 0.0°. It may increase to 1.3 for either the bending moment at higher crossing speeds or at more extreme ramp slopes for the shear force in the ramp. These effects can extend up to one vehicle length towards the center of the bridge and should be investigated.

5.3.6 Eccentricity. Bridge design will provide for normal crossing of the load, *V*, anywhere on the roadway surface. The critical position will be that which produces the greatest stress conditions as determined by static analysis. Bridge cross slopes and deflections and movement of the vehicle center of gravity (CG) must be allowed for.

5.3.7 Spacing. Design will be based on a minimum clear distance between vehicle ground contact points of 30.5 m (100 ft) or more if critical during the crossing of rated loads.

5.3.8 Braking and Acceleration. Braking and acceleration forces, *B*, of the braking factor times vehicle load, *V*, will be included as a longitudinal horizontal load. Tracked vehicle skewing forces of 0.1 times vehicle load, *V*, will be included as a transverse horizontal load (braking and skewing forces are not additive). The vehicle load, *V*, does not include the impact factor in these cases. These loads are assumed to act at the deck surface. The braking factor is reduced for more than one vehicle on a bridge as follows:

No. of Vehicles on Bridge	Total Braking Factor
1	0.65
2	0.9
3	1.15

Braking factors are bridge system and material dependent. The braking factor for materials other than between aluminum and rubber must be determined through testing.

5.3.9 Footwalk. Footwalks will carry the uniformly distributed load, *F*, shown in the design parameters.

5.3.10 Curbs. Curbs may be provided to prevent vehicles from sliding off the bridge deck surface. If provided the curbs will be designed to withstand at least a force of 0.1 times the maximum hypothetical wheeled axle load. This force will be applied to the curb assuming the maximum projected tire area for the hypothetical tire and the maximum tire pressure. If the contact area is insufficient to apply the design load then it may be considered that the remainder of the load will be applied through tire membrane action.

5.3.11 Wind.

5.3.11.1 The appropriate wind load, *W*, will be applied to the bridge during construction, launching, and recovery; to the completed bridge and vehicle(s) during crossing; and to the bridge alone (maximum wind load). Wind velocities and pressures are given in the design parameters (Section IV, DESIGN PARAMETERS).

5.3.11.2 The wind pressure, W_P, is determined from the following formulas:

$$
\begin{aligned}
W_P \;=\;\; & 0.613v^2 \text{ N/m}^2 \text{ with } v \text{ in m/s.} \\
& 0.0625v^2 \text{ kp/m}^2 \text{ with } v \text{ in m/s.} \\
& 0.00347v^2 \text{ lbf/ft}^2 \text{ with } v \text{ in knots.}
\end{aligned}
$$

5.3.11.3 Allowance must be made for the type of bridge construction, drag, shadow effects, and angle of incidence. It may be necessary to consider a lower MLC vehicle/maximum wind area in Section IV, DESIGN PARAMETERS. The following drag coefficients should be used unless more accurate values are established: Bridge and launching structure, 1.6 and vehicles, 1.4.

5.3.12 Additional Loads on Floating Equipment. The following additional loads and conditions must be considered for floating bridges, rafts, and causeways:

Grounding pontoons on one side including the effect of vehicle load on the structure, the bottom-skin load given in the design parameters, and the possibility of bridging between two groundings.

Possible locking of articulating connections.

Increasing stress resulting from the fact that on a floating bridge a single vehicle may impose a greater stress than several vehicles at the minimum spacing, and there may be a critical spacing and/or speed related to the natural crossing water wavelength or band-reflected wave trough.

5.3.12.1 On a raft the vehicle loads, *V*, may be concentrated with no spacing and should be considered stationary, neglecting impact.

5.3.12.2 Drag is the horizontal component of hydrodynamic force, *Q*. For a raft this force includes the propulsion force which may act in any direction. For a floating bridge where propulsion units or anchors counteract drag, the following effects must be allowed: failure of alternate propulsion units or anchors; failure of alternate anchors, if the anchor spacing is not less than 14.0 m (45 ft, 11 in); or failure of all anchors. This assumes the remaining propulsion units or anchors can take the increased load. This effect is also considered to cover the effect of floating debris on unprotected structures.

5.3.12.3 Draw down is the vertical component of the hydrodynamic force, *Q*, caused by the shallow-water, fast-current effect.

5.3.12.4 The hydrodynamic forces, *Q*, depend on the configuration of the equipment and the hydrodynamic conditions. Such forces should be determined by theoretical analysis or by model tests. The design parameters give some guidance to hydrodynamic conditions. The hydrodynamic forces, *Q*, can be increased by the following effects: (1) interference of flow caused by little or no clear space between pontoons, increasing the flow velocity under the pontoons and possibly the upstream head; and (2) longitudinal wave formation initiated by vehicles crossing, causing loss of water under the inshore pontoon.

5.3.12.5 The unbalanced load due to ice forming from spray or during launch shall be accounted for by multiplying the exposed surface area to one side of the centerline times 27 N/m^2 (2.75 kp/m^2, 0.56 lb/ft^2). This represents an ice load of 3 mm (0.12 in) thickness.

5.3.13 Pier Load. A pier shall be considered as a clear-span bridge component allowing for the hydrodynamic loads at the specified currents speeds. The current direction should be allowed to deviate 20.0° from the normal line of approach.

5.4 Load Combinations. See paragraph 2.2, Symbols, for definition of symbols. See Section VI, SAFETY for details of the functions below.

5.4.1 Clear-Span Bridges.

5.4.1.1 During construction, launching, and recovery:

$$P = \mathrm{R}(D, W, M)$$

Launch drive loads and working parties must also be considered.

5.4.1.2 In Place:

For normal bridge use, $P = \mathrm{R}(D, V, W, M, B, F, S)$
For unloaded bridge survival, $P = \mathrm{R}(D, W, M, S)$

Survival is no permanent set or overturning.

5.4.1.3 Bridges with Piers. In addition, the horizontal components of the hydrodynamic force, Q, must be considered in the above load combinations.

5.4.2 Floating Bridges and Rafts.

5.4.2.1 During construction, launching, and recovery:

$$P = \mathrm{R}(D, Q, W)$$

5.4.2.2 In Place:

For normal use, $P = \mathrm{R}(D, V, Q, W, M, S, B, F)$
For unloaded survival, $P = \mathrm{R}(D, Q, W, M, S)$

THIS PAGE INTENTIONALLY LEFT BLANK

VI. SAFETY

6.1 General. Safety is covered as follows: derivation of the design load; safety coefficients for working stress; flotation and stability; fatigue safety factor; and safety against overturning or rotation.

6.2 Design Load (*P*). The design load, P, is derived as follows using the appropriate load combination of dead load, D, and applied loads, A_1, A_2, in order of decreasing severity (where A_2 is the largest of any secondary loads):

$$P = D + A_1 + A_2$$

This means that all loads after the third are ignored. They are generally not significant when compared with A_1, and all the loads are unlikely to reach extreme values together. Vertical and transverse load cases are to be considered as these may have different orders of loads. Similarly there may be different orders of loads for different components. For preliminary analysis, dead load, D, and vehicle load, V, may be factored by 1.15 at Military Load Class (MLC) 30 to cover all other loads. For higher load classes, this factor can be linearly reduced down to 1.075 at MLC 60 and above.

6.3 Safety Coefficients and Combined Stresses for Metal.

6.3.1 Allowable Stresses. The design load, P, will not cause stresses exceeding the following appropriate values.

6.3.1.1 Bending and/or Tension. The lesser of the following will be used:

$$\frac{\text{Ultimate Strength}}{1.5} \text{ or } \frac{\text{0.2\% Proof Stress or Yield Stress}}{1.33}$$

6.3.1.2 Shear. The value from 6.3.1.1 multiplied by 0.6.

6.3.1.3 Bearing. The value from 6.3.1.1 multiplied by 1.33.

6.3.1.4 Buckling. Where failure can occur because of buckling, the following allowable stress will be used:

$$\frac{\text{Buckling Stess}}{1.5}$$

6.3.2 Combined Stresses.

6.3.2.1 Calculation is based on linear elastic theory.

6.3.2.2 Combined axial stresses due to bending and axial tension or compression, or additive axial stresses due to bending in two planes at right angles will satisfy linear superposition:

$$S(\text{Actual Axial Stresses due to Design Load, } f_x) \leq \text{Allowable Stress}$$

For compression, buckling may also have to be checked.

6.3.2.3 Yielding Theories of Failure:

For materials with ductile behavior, Octahedral Shearing Stress Theory will be used:

$$f_v = \sqrt{f_x^2 - f_x f_y + f_y^2 + 3 f_s^2}$$

f_v may not be greater than 0.9 times the allowable stresses.

For material with brittle behavior, Maximum Principle Stress Theory will be used:

$$f_v = \frac{\left(f_x + f_y\right) \pm \sqrt{\left(f_x - f_y\right)^2 + 4 f_s^2}}{2}$$

f_v may not be greater than the allowable stresses.

6.3.3 Limit State Design (LSD) (Provisional). Structures will satisfy both the Overload Check and Ultimate Check, as defined in Appendix I - LIMIT STATE DESIGN (Provisional).

6.4 Safety Coefficients at Working Load (*P*) for Composites and Adhesives.

6.4.1 Safety Coefficients for Working Conditions for Composites. The design load, *P*, shall not cause stresses or strains exceeding the following appropriate values.

6.4.2 Allowable Strain. Under the maximum working load, the strain in any fiber direction should not exceed 50% of the minimum guaranteed fiber strain.

6.4.3 Multiaxial Stresses. The stress level in a lamina should be limited based on an appropriate lamina failure criterion, incorporating a safety margin. The Tensor Polynomial Hoffman-Hill criteria or Tsai-Wu criterion as given next may be used. Alternative criteria must be shown to be appropriate prior to application. It might be necessary to consider other than first ply failure:

$$1.5\,(T_1 f_1 + T_2 f_2) + 1.5^2 (T_{11} f_1^2 + T_{22} f_2^2 + T_{33} f_3^2 + 2 T_{12} f_1 f_2) \leq 1$$

where 1.5 is the safety factor using A-values. If A-values have not been established, 1.2 x 1.5 = 1.8 should be used.

f_1 = normal stress in fiber direction.

f_2 = normal stress perpendicular to the fiber in the plane of the lamina.

f_3 = in-plane shear stress.

T_1, T_2, etc., are strength parameters determined by test.

$$T_1 = \frac{1}{X_T} - \frac{1}{X_C},\ T_2 = \frac{1}{Y_T} - \frac{1}{Y_C},\ T_{11} = \frac{1}{X_T X_C},\ T_{22} = \frac{1}{Y_T Y_C},\ \text{and } T_{33} = \frac{1}{U_S^2}$$

T_{12} cannot be determined unambiguously; T_{12} may be taken as zero or $-1/2\sqrt{T_{11}T_{22}}$ unless there exists specific information to justify a different value. X_T, X_C, Y_T, and Y_C are the minimum tensile and compressive failure strength values of the unidirectional layer in directions parallel to and perpendicular to the fiber directions, and U_S is the minimum in-plane shear strength. In addition to the limitation on ply stress level, the tensile and compressive stress levels in the laminate composite should be limited to 2/3 of the corresponding minimum guaranteed laminate strength levels.

6.5 Flotation and Stability. The safety of floating bridges and rafts depends also on reserve flotation and stability. Since these are related to the equipment configuration and usage and to hydrodynamic conditions, exact rules are difficult to make. The following points should be used as a guide.

6.5.1 It is desirable that when flotation is damaged or holed, it should be capable of at least supporting the dead load, *D*, by compartmentalizing or other means. Flotation must be provided for more than the working load, *P*. Approximately 20% reserve of buoyancy in still water is recommended, but load distribution between flotation units also should be considered. Buoyancy shape must allow for wave formation.

6.5.2 Components as they are launched, part assemblies, and the final assembly must have stable equilibrium for normal eccentric loading in the required hydrodynamic conditions. The individual component must accept a load of $1.35P_C$ placed on the gunwale without becoming unstable. P_C is the component stability design load and must include the relevant portion of the dead load, *D*, and the maximum number of soldiers likely to be on the pontoon during construction. For open components when flooded, the load A_1 is a soldier, 0.89 kN (91 kp, 200 lbs) and a pump which can be taken as 0.25 kN (25 kp, 55 lbs) in the absence of a design figure. For complete equipment supporting a vehicle, the empirical factor of safety on stability is that the metacentric height of the loaded flotation must be equal to or greater than 5 times the distance from the equipment centerline to the maximum load class vehicle center of gravity (CG), when the outside line of the track/tire coincides with the edge of the roadway surface.

6.6 Fatigue Safety Factor. See Section VII, FATIGUE.

6.7 Safety Against Overturning or Rotation. During construction, launching, and recovery there must be a minimum factor of safety against overturning or rotation of 1.20. This is assumed to include impact.

6.8 Lifting and Anchorage Safety.

6.8.1 Lifting equipment which has unrestricted use must comply with civilian regulations and be marked with the safe working load.

6.8.2 Lifting eyes should comply with civilian or military regulations and be marked with the safe working load.

6.8.3 Lifting points designed as part of an equipment must have a minimum safety factor for proof load of 3.2 for equipment mass from 230 to 9,080 kg (0.25 to 10.0 tons) or 2.3 for equipment mass more than 9,080 kg (10.0 tons). They must have a minimum safety factor for ultimate load of 4.8 for equipment mass 230 to 9,080 kg (0.25 to 10.0 tons), or 3.45 for equipment mass more than 9,080 kg (10.0 tons). Allowance must be made for the number of points used and/or for the number of items to be lifted. These safety factors include inertia loads due to acceleration.

6.8.4 Tiedown fittings should have a minimum safety factor for proof load of 4 in the fore and aft direction, 2 upwards, and 1.5 in the lateral direction. The ultimate load should be 1.5 times the proof load. A requirement for air transport may also have to be considered.

6.8.5 Steel wire rope cables, slings, and assorted fittings not covered by paragraph 6.8.1 should have a minimum safety factor of 3 on the breaking load.

6.9 Air Transport Safety

6.9.1 Air Portability. Attachment points are required or the facility to provide the following ultimate restraints: forward 4.0 g (an absolute minimum of 3.0 g) is allowed in transport aircraft without passengers. All other horizontal directions are 1.5 g and upwards 2.0 g. 44.50 kN (4,539 kp, 10,000 lbf) ultimate load tiedown chains are used.

6.9.2 Air Dropping. Attachment points are required, or the facility to provide the following ultimate restraints: forward 4.0 g, upward 5.0 g, and all other directions, 3.0 g. The medium stressed platform has 22.24 kN (2,268 kp, 5,000 lbf) ultimate load tiedowns and the heavy stressed platform, 44.50 kN (4,539 kp, 10,000 lbf) ultimate.

6.9.3 Helicopter Lift. A single-lift point must take 4.3 g ultimate. Two points must each take 2.2 g; three points, 1.5 g, and four points, 1.25 g ultimate. Ideally, a four-leg sling should be used with the lift points as far from the CG as possible and above it. The included angle of the sling is not to exceed 120°. The load should include down draught (maximum value is 0.287 kN/m^2, 29.0 kp/m^2, 6.0 lbf/ft^2) allowing for fuselage shadow. Drag and negative lift must also be considered.

THIS PAGE INTENTIONALLY LEFT BLANK

VII. FATIGUE

7.1 Scope. Design based on Sections V, LOADS AND LOAD COMBINATIONS and VI, SAFETY may not result in adequate fatigue life. Structures must be checked or designed in accordance with this section, and the required life must be confirmed by test as required by Section VIII, TESTING. The material fatigue data requirements are in Section III, MATERIALS. Section VII, FATIGUE, covers: load spectrum parameters, fatigue design load range, damage tolerant design, and alternative designs. Appendix H - SAFETY FACTORS ON REQUIRED LIFE *n* FOR DESIGN AND TEST, summarizes the safety factors given in this and the following section, Section VIII, TESTING.

7.2 Load Spectrum Parameters.

7.2.1 The following parameters affect the fatigue life of military bridges and their launching equipment. The combined parameters, with the frequency of application, form the load spectrum.

Vehicle spectrum, number of crossings with actual laden vehicle weights.

Gap/span spectrum with associated number of crossing vehicles.

Number of launches.

Impact.

Eccentricity.

Bridge support conditions.

Modular bridge component location variation with each build.

7.2.2 Information is not available at present for all of the above parameters, and it is not possible to obtain load spectra for military bridges. For the present, the life required will be expressed as a specified number of crossings, *n*, of the maximum load class over the maximum span of the bridge and a specified number of launches. No approximate launching load spectrum has been established.

7.2.3 When modular bridges can be constructed in different forms and various Military Load Class (MLC)/span combinations, the most fatigue-damaging construction based on normal usage and stress level should be considered.

7.2.4 Use for different MLCs and bridge spans may be related approximately to the constant amplitude parameters, stated in paragraph 7.2.2, by the Palmgren-Miner or linear damage rule:

$$\frac{n_1 \text{ crossings (cycles at sress } f_1)}{N_1 \text{ (fatigue life at stress } f_1)} + \frac{n_2 \text{ crossings (cycles at sress } f_2)}{N_2 \text{ (fatigue life at stress } f_2)} + \ldots + \frac{n_i \text{ crossings (cycles at sress } f_i)}{N_i \text{ (fatigue life at stress } f_i)} \leq 1$$

where the stress f_i and fatigue life N_i are from given MLCs/Spans over which the n_i crossings occur.

Preferably, if a realistic load spectrum can be established, a programmed fatigue test on representative specimens should be used to establish a more accurate damage relationship.

7.3 Fatigue Design Load Range (P_{FAT}). The fatigue design load range, P_{FAT}, is the unfactored vehicle load multiplied by a dynamic factor covering eccentricity and impact. This dynamic factor for design can be established by tests or from experience. From current equipment the following mean factors may be used: clear-span bridges, 1.075; link reinforcement, 1.15; and floating bridge girders, 1.035. It is assumed that applied loads other than vehicle loads are not significant and bridge supports are generally level. Certain components may have to be designed for other load conditions. A factor for launching loads still has to be established.

7.4 Damage Tolerant Design. (Metals only. Special consideration for composites.)

7.4.1 Because of the scatter in fatigue performance and the possibility of use beyond the required minimum life, there is a risk that a bridge will fail in service. Damage-tolerant design should ensure that when fatigue cracking occurs in service the remaining structure can sustain the maximum working load P without failure until the damage is detected. A safety factor of 1 is acceptable. (The same should apply to corrosion or accidental damage.)

7.4.2 The stress range due to the fatigue design load range, P_{FAT}, will not exceed the stress range from the most suitable minimum curve for stress/number of cycles (S/N) at 1.5*n* or from the most suitable mean curve at 1.5 x 1.5*n* (2.25*n*). In addition, a check must be made to ensure that the maximum stress due to the design load, *P*, does not exceed the lower value of the allowable stress from Section VI, SAFETY. If possible it should be established that for a particular detail, the factor should be 1.5 on minimum or 2.25 on mean.

7.4.3 The following design features should be used to achieve damage tolerance:

Selection of materials and stress levels to provide a low rate of crack propagation and long critical crack length.

Provision of multiple load paths.

Provision of crack-arresting details.

Provision of readily inspectable details.

Establish a fracture control plan for safe life and safety critical components which are not fail safe, giving inspection methods, material data requirements, assumed initial crack size, required inspection frequency, and the like.

7.4.4 Damage tolerance depends on the level of inspection the user is prepared to apply to the structure and is not automatically ensured by replaceable components. Inspection of equipment must be planned to ensure adequate detection and monitoring of damage and to allow for repair or replacement of components. This must be confirmed during testing (Section VIII, TESTING). The following factors must be considered:

Location and mode of failure.

Remaining structural strength.

Detectability and associated inspection technique. (This should be based on the largest flaw not likely to be detected rather than the smallest it is possible to find.)

Inspection frequency.

Expected propagation rate allowing for stress redistribution.

Critical crack length before repair or replacement is required.

7.4.5 It may be necessary to test fatigue critical components or details in the laboratory, particularly if suitable minimum curves are not available or the mode of cracking cannot be anticipated. If there are a limited number of samples, or a structure is tested, so that there is only one failure from a number of equally loaded samples, the required life factor from the table given in paragraph 8.8.4 should be used. The test results can be analyzed statistically if there are five or more samples. The lowest sample life to failure should be at least the minimum design life (1.5*n*).

7.4.6 If a component, or a structure subject to the same loading, includes a critical safe life element (see paragraph 7.5, Alternative Designs) that relies on a damage tolerant element to indicate that fatigue life is expended, the minimum life of the safe life detail must exceed the maximum life expected from the damage tolerant detail.

7.5 Alternative Designs. Damage tolerant equipment is preferred. The most economic structure should be produced if it is designed to a minimum required life and provision is made for regular inspection. However, there may be cases where regular inspection is not possible or the user does not wish to take on the commitment and the resulting penalties are acceptable. There are then three further design systems which can be used. THEY ARE NOT GENERALLY RECOMMENDED UNLESS SPECIFICALLY REQUIRED BUT ARE INCLUDED TO SHOW THE ALTERNATIVES AVAILABLE.

7.5.1 **Monitored Usage Safe Life**. Regular inspection for fatigue cracks is not required or may not be possible. The design and test factors for damage tolerant design are used but to allow for monitoring and cumulative cycle ratio errors, the design life is factored by an additional 1.5 giving 2.25*n* on a minimum curve or 3.37*n* on a mean curve. The component or equipment must be replaced once monitoring shows the user's required life has been reached. Repair of fatigue damage is not permissible and damage tolerance is not essential.

7.5.2 Unmonitored Safe Life. If inspection and monitoring use of an equipment or component is impractical or is not accepted by the user, it is necessary to ensure safety from possible catastrophic failure by increasing the user's required life by a factor of ten (10*n*). This also covers variation in the load spectrum during the life of the equipment. Although the user is absolved from checking usage of the equipment, only the life requirement of *n* is guaranteed. This does not automatically mean a longer life. If the load spectrum is going to be unchanged through the service life, 6.7*n* may be used. The stress range due to the fatigue design load range, P_{FAT}, will not exceed the stress range from the most suitable minimum curve for S/N at 15*n* (1.5 x 10*n*) or from the most suitable mean curve at 22.5*n* (1.5^2 x 10*n*). If the load spectrum will be unchanged, the stress range at 10.0*n* with a minimum curve or at 15.75*n* with a mean curve may be used. In addition, a check must be made to ensure that the stress due to the design load, *P*, does not exceed the lower value of the allowable stress from Section VI, SAFETY.

7.5.3 Infinite Life. This is generally recognized as designing to the asymptotic stress from the most suitable minimum curve for S/N which is taken as that at $n = 1\text{x}10^7$ cycles for steels or 2 x 10^6 cycles for aluminum alloys; or the static safety coefficient of 1.33 (paragraph 6.3.1) can be applied to the stress from the mean curve for material at these cycles. Stress levels must be checked by test, and a confirmatory fatigue test is desirable. Infinite life is rarely used, as unmonitored safe life normally satisfies the user's requirement.

7.5.4 Application of fracture mechanics is recommended by assuming an undetected initial crack at the most unfavorable place (e.g., lug, bolt) of a critical component. This crack must not exceed the critical crack size during a design life to be defined. Otherwise, a change in design, material, or inspection is necessary giving a damage-tolerant design. If this is not possible, field inspection is required giving monitored safe usage life design.

VIII. TESTING

8.1 General. Testing must be undertaken in order to confirm that equipment satisfies the requirements of the user and this Code and to validate the design. Testing should identify all critical features and failure modes. Testing should also cover environmental effects on equipment use, in storage and life, especially if degradation is possible. Accelerated testing should be relatable to actual life. Crossing equipment may not be a single structure but a complex assembly and the checking of performance must relate to the compatibility of the equipment as a system. The following tests are considered: requirement test, structural strength test (static), trafficking, additional tests for floating equipment, fatigue (dynamic), and test during production. Troop trials are not covered.

8.2 User Trials/Performance Tests. Equipment must pass the relevant tests and then be approved by the User, through User trials/performance tests, before acceptance into service.

8.3 Dual Testing. It is preferred that structural strength tests are carried out first on one equipment, and then concurrently trafficking and the fatigue test are carried out in parallel, as considered necessary.

8.4 Requirement Tests. Complete systems and components must be tested to show that the user requirements and the relevant design parameters in this Code are met. Testing will include construction, launching, recovery, and transport. It must be shown as far as possible that equipment will perform satisfactorily in field-service conditions and that equipment can be stored and used in the required environmental conditions.

8.5 Structural Strength Tests.

8.5.1 Equipment and components must be tested to show that there is at least the safety margin required by this Code between the working load, P, and the onset of unacceptable permanent distortion in the structure, and that no unforeseen structural behavior occurs. This is achieved by the overload test. It is essential that an overload test is carried out on complete structures. It also should be shown that allowable stresses are not exceeded at the working load, P, in areas free from stress concentrations. It will generally be necessary to carry out vertical and transverse loading tests. It is desirable that an ultimate load test is carried out on critical components and preferably on complete structures.

8.5.2 The test load used will be the most severe combination of loads for which the components or structure has been designed. Test loads should be applied in such a manner that the local effects and deflections produced by the actual loads in use are reproduced as closely as possible. The applied test loads and the structure should be given, as far as possible, the same degree of freedom as actually occur in the field in order to minimize spurious restraining loads that would otherwise be induced as the structure deflects and rotates.

8.5.3 If it is impractical to reproduce all the applied loads, the required effect may be produced by simulated loads or by increasing the value of other loads, providing this does not affect the validity of the results.

8.5.4 If a load on a different axis produced 5% or less of the total effect being examined and is difficult or expensive to apply, it can be omitted provided stability is not affected and the omission is stated and allowed for in the test report.

8.5.5 A structure or component under test must be supported so that accurate measurements of strain deflection and permanent set can be made.

8.5.6 The effect of actual in-service bearing and support conditions must be covered in other tests. Components also must be supported as they would be in the complete structure.

8.5.7 The structure or component must be tested at the most disadvantageous, in-service, geometric conditions allowed in design.

8.5.8 In addition, it may be considered desirable to check that a structure can accept, with a lower factor of safety, more extreme geometric or loading conditions than are allowed in design if occasional specific misuse in service can be envisaged.

8.5.9 Working Load Test.

8.5.9.1 This may be a separate test or may be allowed to continue into the overload test.

8.5.9.2 The critical value of the design load, *P*, defined in Sections V, LOADS AND LOAD COMBINATIONS and VI, SAFETY will be applied to the structure. The load should be applied in sufficient number of increments and decrements to determine that the structure is behaving in a linear elastic manner

8.5.9.3 Each increment of load will be held for 2 minutes, after which measurements of deflection and strain will be recorded.

8.5.9.4 Net stresses are not to exceed the allowable working values given in this Code. Stresses for repeated applications of the load shall be consistent.

8.5.9.5 Once the structure has settled down, there shall be no permanent set on pinholes or deflections because of further application of the design load, *P*.

8.5.9.6 The structure will be examined before proceeding to the overload test to confirm to the designer that there is no unacceptable cracking, loosening, or pulling of mechanical fasteners; structural deformation; or other signs of unserviceability. The structure should remain within dimensional tolerances.

8.5.10 Overload Test.

8.5.10.1 The test overload, *O*, will be the critical values of the design load, *P*, from Sections V, LOADS AND LOAD COMBINATIONS, and VI, SAFETY multiplied by the safety factor 1.33. The load, *O*, will be applied at least 3 times up to a maximum of 10 times.

8.5.10.2 Before proceeding to the overload test, the structure should be loaded once to working load, *P*, and unloaded before setting instrumentation to zero readings. This procedure is intended to settle supports, joints, and the loading distributing system. It may be omitted if the overload test has been immediately preceded by the working load test.

8.5.10.3 The first load application will be in increments. Each increment of load will be held for a minimum of 2 minutes, after which measurements of deflection and strain will be recorded. Each application of the test overload, *O*, will be held for 30 minutes.

8.5.10.4 The overload, *O*, will be removed, intermediate readings during off-loading will be taken if required, and residual measurements of deflection and strain will be recorded. A recovery period may be allowed if considered necessary, and the residual measurements will be taken again. The load may be taken off at any stage if a check on the onset of permanent set is required. Elastic buckling with no critical secondary effects is acceptable.

8.5.10.5 The structure will be examined to confirm to the designer that there is no unacceptable cracking, loosening, or pulling of mechanical fasteners; structural deformation; or other signs of unserviceability.

8.5.10.6 The test overload, *O*, then shall be applied without increments, up to an additional eight times; maximum and residual deflections and strains are to be recorded.

8.5.10.7 The last, or 10th, application of the overload, *O*, should be made in increments, and the overload, *O*, should be held for 30 minutes. It is necessary only to remove any load distributing system, if required, before and after this last load application so that residual measurements can be determined with the required accuracy.

8.5.10.8 The structure or component will have passed the test, if it passes the conditions of paragraph 8.5.10.5 and if there is no permanent set exceeding the allowable limits given in paragraph 8.5.10.9.

8.5.10.9 The aim of the test is to assure there is no permanent set due to the 10th, or last if less, load application. To ensure a safe structure or component, it is also necessary to limit the permanent set due to the first application of the test overload, *O*. Theoretically, there may be up to approximately 0.2% permanent set on the first load application and none after a few load applications. The gage lengths used must be justified since the structure will not encounter the overload, *O*, in normal service. There will be some settling of connections. Some permanent set can be allowed without causing subsequent problems.

8.5.10.10 If a component or structure does not satisfy the permanent set limits for the first application of the test overload, it must then be shown that it can take at least the ultimate load, *U*, after allowing for dimensions and material values.

8.5.10.11 If a structure or component shows no or very little permanent set, the test overload, *O*, may be increased to establish a higher rating and satisfy Section IX, AVOIDANCE OF OVERWEIGHT DESIGN.

ALLOWABLE PERMANENT SET

Deflections and Gage Lengths		On First Application of Test Overload, *O**	Due to the 10th or Last, if Less, Application of Test Overload, *O**
Item 1.	Connections, Pinholes, pins where local yielding, bearing and settlement can occur.	0.4% and not to exceed 0.5 mm (0.02 in)	0.2% and not to exceed 0.1 mm (0.004 in)
Item 2.	Deflections and gage lengths.	0.2% and not to exceed 1.0 mm (0.04 in)	0.1% and not to exceed 0.25 mm (0.01 in)
Item 3.	Deflections which are a summation of permanent sets.	0.4% and not to exceed 2.0 mm (0.08 in)	0.2% and not to exceed 0.5 mm (0.02 in)

Permanent buckling due to the last application of the test overload is not acceptable in a compression member that has no alternative load paths.

Items 1 and 2 need not be checked if the requirements of Item 3 are met. However, other specification requirements for a particular equipment may necessitate the checking of Items 1 and 2.

* Percentages are expressed in relation to gage length for extensions or maximum deflection for deflections.

8.5.11 A component or structure can be modified or repaired at any stage during the structural-strength testing, but it must pass the complete overload test in its final form.

8.5.12 Ultimate Load Test.

8.5.12.1 The ultimate load capacity for an equipment or structure or component should be established but is not mandatory.

8.5.12.2 The load, *U*, will generally be established by increasing the load at the critical position without the other applied loads and with level bank-seat supports. The designer must establish the critical components and load position considering transverse and longitudinal effects and combinations of bending and shear. The amount of vehicle eccentricity and inclined support effect to be applied must be carefully considered.

8.5.12.3 The ultimate load, *U*, is the maximum load.

8.5.12.4 For an equipment or structure the limit of use may occur before the ultimate load, *U*, is reached due to distortion. The load limit when an equipment or component is not recoverable and/or cannot be reassembled is of interest, but may not be the ultimate load, *U*.

Failure of a structure has not been reached when individual components fail which do not cause failure of the whole structure or stop it being used.

8.5.12.5 The load shall be applied in regular increments no greater than the increments used in the overload test. Each increment of load should be held for 5 minutes after which measurements of strain and deflection will be recorded. The load at which permanent set becomes unacceptable must be established if not already covered by the overload test. The structure must be carefully examined for any signs of incipient failure due, for example, to buckling or weld tearing that may not be obvious from the readings being taken. The calculated ultimate load, U_C, should be held for 30 minutes. It is expected that this load will be exceeded. If the ultimate load capacity is required to be established, then the calculated ultimate load, U_C, is strictly an acceptance condition in that it must not be less than the requirements of paragraph 6.3.1. Failure may not be in the expected mode so careful observation is required. This may be aided by loading under displacement control.

8.5.12.6 The ultimate load capacity from the test is not representative for the whole population because of the variability of the material tested, the geometrical variability, dimensions of failed sections, residual fabrication stresses, and the limited sample.

8.6 Trafficking Tests.

8.6.1 To demonstrate that vehicles have no difficulty in crossing the bridge and that no oscillations or deflections occur that could cause damage or limit crossing, the tests will be conducted wherein a number of vehicles likely to use the bridge will cross in both directions at varying speeds up to the maximum possible as defined in paragraph 4.2.9. These tests should be used to establish the working-stress data caused by impact and eccentricity. Crossings also will be made at the extreme longitudinal and transverse slopes allowed with mud and, if possible, snow and ice on the deck. These tests shall be carried out on a representative bank seat conditions at minimum and maximum spans.

8.6.2 Deck-wear tests will be carried out to show that the deck system will have an acceptable life span. The vehicles should include the most aggressive tracks as well as the most common crossing vehicles. Gravel and stones shall be placed on the deck in order to check for puncturing.

8.7 Additional Floating Equipment Tests.

8.7.1 Requirement tests for floating bridges and rafts will include stability and flotation. A raft must be tested to show that it is stable when steered in all directions - in the maximum current if possible - and that control is not lost when it rotates. Clear-span parts, joints, connections, and, as far as possible, the structure and components should be given an overload test. After the test overload, O, slight buckling of the pontoon skin is acceptable providing it remains watertight and usable. There are, however, two major problems in testing floating equipment: (1) flotation may not be sufficient to carry the test overload, and (2) it may not be possible to cover the range of hydrodynamic conditions.

8.7.2 A load test will be carried out in still water to the limit where there is no freeboard. If safety permits, the test may be carried further, but it should not exceed the overload test condition.

8.7.3 At least one full system test will be carried out with hydrodynamic conditions as near as possible to the most severe or critical.

8.7.4 A stability test is performed to determine the floating structure's righting moment for roll angles up to the point where capsizing is imminent. Tests should be run for both loaded and unloaded conditions in still and fast water. The laden weight and center of gravity (CG) must be established by relating the loads and their positions to the unladen conditions determined first. Heel angles should be increased by approximately 2.0° increments until the heeling force (usually applied by pairs of cables that do not affect buoyancy), drops off sharply. This indicates approaching instability/capsizing, and the test is stopped. For a structure with adequate stability, the heeling may be limited at the discretion of the designer.

8.8 Fatigue Tests.

8.8.1 At least one complete bridge should be tested by trafficking with a range of vehicles which are representative of those that will use the bridge and produce the fatigue design loading conditions. Decking and cross-girders could require wheel or axle loadings which are not given by a tracked vehicle. Trafficking is necessary because it is not normally possible to reproduce in the laboratory all of the conditions caused by a rolling load and the interaction of bridge components at all locations or vibration loading.

8.8.2 The trafficking test should be carried out over the range of vehicle speeds that will occur in service for at least a total of n cycles or crossings and desirably up to 1.5n. Impact and eccentricity will occur naturally. A field trial is the only comprehensive test covering all possible fatigue critical areas and all loading arising from the crossing vehicle. A test in the laboratory requires the engineer to identify the fatigue critical area(s).

8.8.3 If the test is continued in the laboratory, actual stresses measured at particular locations as the bridge is crossed should be reproduced instead of the fatigue design load range, P_{FAT}. Laboratory testing must load the fatigue critical areas, and tests at several load positions may be necessary to cover different details and/or bending and shear. Due to the symmetry of a structure about its major axes and the repeated details along the length, there will be two or more fatigue critical detail samples. It may be possible to increase the number of samples tested by adjusting the position, contact area, and magnitude of the load so that the samples are all correctly loaded, provided transverse loading due to differential deflection is not critical. All details considered part of a sample must be justified by the measurement of strain or load distribution or accurate detailed analysis.

8.8.4 It is normally not possible to test more than one or two complete structures and, because there can be considerable differences in performance of nominally identical structures when subjected to the same fatigue loading, there is still a risk that the worst structure will have a life less than the design life.

The fatigue test load shall be applied to the structure for at least the design life, 1.5*n*, without repairs or replacements being necessary. The test must also be continued to determine the eventual mode of failure and so that cracking and inspection techniques can be confirmed or alternatives prescribed to ensure damage tolerance. The test life required for the number of equally stressed samples being tested is obtained by factoring n using the following table for military bridges allowing 95% confidence of 95% exceedance. The accepted value of σ used is log 0.176*.

Number of Samples Tested	**1**	**2**	**4**	**6**	**8**	**9**	**10**	**100**
All samples failed, factors n log mean assuming population standard deviation log 0.176.	3.80	3.12	2.73	2.55	2.48	2.44	2.40	2.09
First sample to fail with population standard deviation assumed as log 0.176.	3.81	2.67	2.01	1.75	1.60	1.54	1.54	0.91

In fatigue test of bridges, usually a set of identical components stressed very similarly is present. So, several samples are tested. When one sample fails, the second line of the table applies.

If the bridge lasts for the factored number of cycles, it is considered to have met the life requirement. When failure occurs at a life between 1.5*n* and the factored number of cycles, the designer must show that the structure is a worse-than-average sample and that there is not a design or production fault. An example would be if the bridge stresses at the location of failure agree in detail with design stresses and if the specimen adequately represents in detail the bridge in material, geometry, and fabrication technique.

Alternatively, a minimum life can be calculated from first principles using test results of components or structures using a test factor derived by a method such as shown in MIL Handbook 5C, Chapter 9, or the values given in Table 9.6.4.1 of that Handbook. This must take into account: the upper limit of exceedance and the degree of confidence, and the number of samples and variations allowed compared with the final production population (e.g., different batches of material from different suppliers, different manufacturing equipment, different operators, different factories, and changes with time).

8.8.5 During the trafficking and laboratory tests, regular inspections must be carried out including those proposed for use in service. Cracks should be allowed to grow and be monitored to investigate:

---

* Sample (for fatigue testing) **-** For large components and in order to increase the number of samples tested, it may be possible to consider that there is more than one sample of the fatigue critical detail, providing the geometry and loading are identical and the onset of cracking of one sample does not influence the loading of any other sample. Symmetry of a structure and repetitive details along a structure can be considered, providing the loading is symmetrical.

Possible variations in crack growth rate.

Frequency of in-service inspections.

Cracks becoming detectable soon after an in-service inspection.

The effect of non-detection of a crack at an in-service inspection.

This information should be used to establish the final form and frequency of in-service inspections and to assess remaining working life.

8.8.6 At all times during the test, the structure must be capable of withstanding the fatigue design load range, P_{FAT}, increased to an equivalent of the maximum working load, *P*, for the fatigue critical section without collapse. This should be confirmed at regular intervals and at the end of the test. If periodic application of a high load improves the fatigue life, allowances may have to be made for this effect.

8.8.7 At no time before or during the fatigue tests should loads higher than the maximum working load, *P*, be applied to a component or structure unless it forms part of the specified acceptance or in-service proving procedure, in which case it should be included in the test. Any overloading beneficial to fatigue life must be disclosed.

8.8.8 Cracks that are practical and economical to repair may be repaired before they endanger the structure or other components by deformation or collapse, providing the repair can be carried out during service. Similarly, components may be replaced if practical and economical. Uneconomical repairs or replacements may be made during a test to prove other parts of an equipment.

8.8.9 If there are changes between prototype and production that could reduce the fatigue life or transfer failure elsewhere, early production equipment or components must be tested to establish that the life requirement is still satisfied.

8.8.10 Equipment designed for safe life must be tested to show that the required life, multiplied by the appropriate factors from the table given in paragraph 8.8.4, is satisfied. The test may also be continued to 1.5*n* for monitored usage, 6.7*n* for unmonitored constant load spectrum, and 10*n* for unmonitored usage multiplied by the appropriate factor from the table given in paragraph 8.8.4 to show the design assumptions have been achieved. The inspection requirement (paragraph 8.8.5) and in-service repairs (paragraph 8.8.8) are not applicable, but still may be used in case the structure fails to meet these life requirements and is accepted as damage tolerant.

8.9 Resonance. During testing it should be confirmed that the natural frequencies of a bridge, part bridge, or component are such that they will not be made to resonate by construction or use. Similarly, there should be no resonance due to wind or water vortex shedding.

THIS PAGE INTENTIONALLY LEFT BLANK

IX. AVOIDANCE OF OVERWEIGHT DESIGN

9.1 General. Minimum weight should be a design aim, but it must be balanced with producing economic, robust equipment that will survive in-service use and misuse. On modular bridging equipment the designer should try to anticipate extension of use during development and increased loadings that could result on certain components.

9.2 Prototype Structure. An early prototype structure should show generally that the working or allowable stresses are reached in the working-load test. Allowances may have to be made for eventual deck wear and increased residual stresses and stress concentration of increasing permanent set when the applied load is increased above the test overload, *O*, and before 1.1 times test overload, *O*, is reached. If permanent set occurs only above this, the structure should be modified and retested, unless there are good structural or economic reasons for accepting the overdesign. The applied test load should be related to actual material properties, allowing for the minimum if there is variation in the different sections used in the structure:

$$P_{\text{TEST}} = P\left(\frac{f_{\text{t}}(\text{Material in Test})}{f_{\text{t}}(\text{Material Specification})}\right)$$

9.3 Fatigue Considerations. If fatigue governs design, the working stresses may be reduced, and the structural strength tests will not be critical. Nonetheless, the designer must check stresses in the structure at this stage. The fatigue test is difficult to use to show overdesign because of scatter of test results and the expense of running further tests. Component or detail laboratory testing should be used with the correct loading as far as possible. Longer life than the requirement must be balanced with the economics of possible weight savings and further fatigue testing.

9.4 Economic Considerations. Should tests show the structure to be overdesigned, changes should be made only if it is economical to do so and if it is certain that the changes will not jeopardize the durability, ease of assembly, and other characteristics established as satisfactory on user or other trials.

9.5 Modification. It should be noted that it is generally easier to reinforce a structure or component than it is to reduce weight.

THIS PAGE INTENTIONALLY LEFT BLANK

X. ADDITIONAL CONSIDERATIONS FOR COMPOSITE STRUCTURES

10.1 General. The following must be considered:

10.1.1 Design verification should include additional failure effects relating to laminate behavior such as interlaminar shear and edge effects.

10.1.2 Temperature Effects. Normally a composite would not be selected which would be significantly affected by temperature over the range of working temperatures. If this cannot be achieved, tests must be carried out in the most disadvantageous conditions that could be experienced. Weapon effects must be considered. Thermal stresses in hybrid structures with different moduli of elasticity and/or coefficients of thermal expansion must be considered. Temperature cycling effects are to be considered.

10.1.3 Surface damage due to roller, wheels, tracks, or stones.

10.1.4 General and local impact damage due to severe mishandling which can cause interlaminar cracks not seen by the eye.

10.1.5 Environmental degradation particularly due to moisture absorption and ultraviolet degradation.

10.1.6 The possible effects of galvanic corrosion and thermal cycling for hybrid structures constructed of metals and composite materials.

10.1.7 Fatigue life, even if the basic material has an asymptotic stress on the stress/number of cycles (S/N) curve, stress concentration, and joints must be investigated. Carbon composites have a good fatigue life when loaded axially in tension; however, when the matrix contribution to load resistance is significant, fatigue lives are only comparable with that of metals. Under cyclic loading composites are less sensitive to notches than metals. In static loading they are more sensitive to notches than metals. Fatigue failure should be defined in terms of loss of stiffness as well as onset of cracking.

10.1.8 Toxicity and flammability during fabrication and in-service use.

10.2 Testing.

10.2.1 Structures and components should undergo sustained loading to ensure that the full working load without impact can be maintained for at least 12 hours without unacceptable creep.

10.2.2 For the overload test (paragraph 8.5.10), the overload factor should be increased to 1.5 in order to ensure that there is an adequate reserve on the calculated ultimate load, U_C, since there is unlikely to be noticeable yielding or non-linearity.

10.2.3 Where components include metal joints or parts, it must be decided whether some deformation is acceptable between 1.33*P* and 1.5*P*. Yielding and some deformation is accepted in areas not in contact with composite material.

XI. RELIABILITY, AVAILABILITY, AND MAINTAINABILITY

11.1 General. This Code is largely concerned with structural design and its validation. Reliability, availability, and maintainability (RAM) must also be considered to ensure that equipment is capable of repeated transportation, erection, use, dismantling, and reuse under field conditions, and that it can be easily repaired. Structural design and fatigue testing are performed to high levels of exceedance and confidence. The same can be expected of component/system mechanical reliability. When reliability is established by carrying out a number of complete mission cycles/battlefield days, it may be necessary, especially for hand-erected equipment, to accept lower levels of reliability and confidence. Reliability trials only can be carried out by troops. There is no relaxation for the number of samples tested except that it can increase the mean-time-between-failure. RAM must be included in trade-off analyses, especially those concerning cost and weight, since it is more cost effective to design in RAM rather than to perform design changes after the equipment is built.

11.2 Failure Modes, Effects, and Criticality Analysis (FMECA). A failure modes, effects, and criticality analysis must be performed for all equipment down to the lowest repairable level early in the design effort. This analysis will be used to identify areas requiring design emphasis to eliminate modes of failure, to incorporate changes to lessen the effects of certain failures, and to provide a basic maintenance strategy for both corrective repair actions and scheduled inspection, which may be required.

11.3 Parts Control and Component Testing. A parts control program will be established to aide in the selection of proven or established parts. The program will encompass**,** as a minimum**,** the hydraulic, electronic/electrical, and mechanical parts used to control and launch/recover the bridge structure. The structural interface of components, linkages, and pins should be selected with the aid of stress-strength analyses. If a fracture control plan, as mentioned in paragraphs 7.4.3 and 7.5.4, is established, it then should become part of RAM. For parts with an unknown reliability data base or newly designed parts, component testing should be performed to verify their acceptability for use in military bridging equipment.

11.4 Stress Derating. Criteria for the derating of both electronic and non-electronic parts should be established at the start of a new design.

11.5 Design Guidelines and Reviews. RAM design guidelines must be established to assist the designers in achieving the user's requirements. All RAM related efforts should be presented at scheduled design reviews with separate RAM reviews held when deemed necessary.

11.6 Models and Predictions. Reliability and maintainability math models should be initiated at the start of a program which represent the functional design as it matures. Predictions should be periodically performed based on the models and FMECA to assess the equipment's capability to meet the user's requirements. Corrective action will be instituted at the onset of noncompliance with these requirements.

11.7 Software Development. Any software developed for use in automatically controlling bridging equipment must be performed in accordance with an established software quality assurance program. The software should be tested separately before integration with the system hardware.

11.8 Maintenance Concept. The design effort must be cognizant of the user's maintenance concept to develop equipment maintainable with the expected skill of user personnel, to facilitate the ease of maintenance, and to limit the use of special tools or maintenance test equipment.

11.9 Desirable Measures of Reliability and Maintainability.

11.9.1 Reliability. The mission reliability should be specified as the mean number of mission cycles before failure which aborts or prevents completion of the missions. The basic reliability should be specified as the mean number of mission cycles before failure which requires a corrective maintenance action.

11.9.2 Maintainability. The equipment maintainability should be specified as a maintenance ratio of maintenance man-hours per mission. The man-hours for both corrective and preventive maintenance should be included in the ratio. An alternative or additional measure would specify a mean time to repair for corrective maintenance actions and a preventive maintenance schedule.

11.9.3 Availability. The measure which should be used is operational availability. This term not only includes operating time and maintenance actions, but accounts for standby time (operable but not in use) and administrative and logistics delays incurred during the repair of the equipment.

XII. BRIDGE CROSSING RATING

12.1 General. This system can be used to increase the load class and/or span under restricted crossing conditions.

12.2 Normal Crossing. A normal crossing is unrestricted use of an equipment within the parameters of this code.

12.3 Caution Crossing. A caution crossing is a crossing of a vehicle class higher than the normal or of a span longer than the normal which is made under restricted crossing conditions. Vehicle speed is reduced with minimum eccentricity and braking and no impact. Only one vehicle is allowed on the bridge at a time. This may not be applicable to floating bridges. Other conditions are the same as normal. A caution crossing develops the same static stress in the structure as the maximum normal crossing.

12.4 Risk Crossing. A risk crossing is a restricted crossing which is made under emergency conditions only. The crossing allows an increase in vehicle load class and/or increases in span beyond caution. The vehicle speed is reduced with minimal eccentricity and braking and no impact. Only one vehicle is allowed on the bridge at a time. Other conditions are the same as normal.

The risk crossing may cause yielding of the equipment but is short of ultimate failure. After a risk crossing it may not be possible to reuse or recover the equipment.

12.5 Probability of Failure.

Rating	Probability of Yield	Probability of Ultimate Failure
Average Crossing	1 in 10^6	1 in 10^9
Normal	1 in 10^4	1 in 10^7
Caution on Yield (at 1.33)	1 in 10^4	1 in 10^7
Risk	1 in 10	1 in 10

12.6 Testing. Tests should be carried out with the actual Military Load Class (MLC) vehicle footprint and/or increased spans. Permitted support conditions and secondary loading must be rigorously applied.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A

METAL DATA SHEETS

A.1 Data sheets of common military bridging materials are provided for information purposes only and are not intended for design. Other materials may also be considered.

A.2 Nomenclature:

A.2.1 Relative Fabrication and Corrosion Codes: The following comparison codes are used:

a - Excellent.
b - Good.
c - Fair.
d - Poor.
X - Not applicable.
a-b - Denotes declining rating with higher tempers.
b-a - Denotes improving rating with higher tempers.

Note: A plus sign following the rating means "better than."
A minus sign following the rating means "not as good as."

The above comparison code definitions are given in "Aluminum standards and data", Table 3.3, Comparative Characteristics and Applications. "Aluminum standards and data" is published biennially by The Aluminum Association Inc., 818 Connecticut Ave., N.W. Washington D.C. 20006.

A.2.2 Symbols:

L - Longitudinal, rolling, or extrusion direction.

T - Long transverse direction.

F_{bru} - Ultimate bearing stress.

F_{bry} - Yield bearing stress.

F_{cy} - Yield compressive stress.

F_{su} - Ultimate shear stress.

F_{sy} - Yield shear stress.

F_{tu} - Ultimate tensile stress.

F_{ty} - Yield tensile stress.

T_{uw} - Ultimate weld strength.

T_{yw} - Yield weld strength.

A.3 Index of Metals.

METAL DATA CHART

Material	National Designation	Country of Origin	Yield Stress (N/mm^2)	Ultimate Stress (N/mm^2)	Elongation (%)	Weldability
Aluminum	2219	US	250-360	370-440	3-6	Yes
	DGFVE 232B	UK	330	385	8	Yes
	MVEE 1318B	UK	315-425	385-465	6-8	Yes
	7005	US	260-310	325-350	7-10	Yes
	AlZnMg1	FRG	120-290	220-360	8-15	Yes
	AlZnMg2	FRG	220-280	320-360	10-12	Yes
	x7046	US	117-375	180-420	13-18	Yes
	7075	US	145-490	275-558	4-10	No
	7020	UK	270	320	8	Yes
	7050	US	365-483	427-545	3-10	Yes
Steel	St 52-3	FRG	340-360	520	22	Yes
	T-1 A514	US	630-700	730-800	17-18	Yes
	18% Maraging	US/UK	1,400	1,460	4-15	Yes
	4340	US	482-1,480	760-1,800	10-22	No

Application:
Missiles and space vehicles, pressure tanks, high-temperature applications.

Designation:
2219

Country:
US

Availability:
- Sheet T31, T37, T62, T81, T87
- Plate T35, T34, T62, T85, T87
- Shapes (Ext.)... T35, T62, T8511
- Tube T31, T81
- Bar T351, T851
- Forgings T35, T6, T851, T87

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... b
- Cold Working - T X
- Arc Welding .... a
- Resistance Welding .... a
- Brazing X
- Machining .... a

Chemical Composition:

Element	%
Si	0.20 max
Fe	0.30 max
Cu	5.8-6.8
Mn	0.20-0.40
Mg	0.02 max
Zn	0.10 max
V	0.05-0.15
Ti	0.02-0.10
Zr	0.10-0.25
Others, ea	0.05 max
Others, Total	0.15 max
Al	Remainder

Properties:*
- Density .... 2,800 kg/m^3
- Spec Gravity ... 2.83
- Thermal Exp .. 22.3 x 10^{-6}/K
- Mod of Elas .... 72 x 10^3 N/mm^2
- Mod of Rid ..... 27.7 x 10^3 N/mm^2
- K_{IC}................. 30 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph A.2)
- General .... d
- Stress Corrosion .... a

National Specifications:
- ASTM B 221-90
- QQ-A-250/30
- AWS A5.10

Joinings:
- Rivet alloys 2219
- Welding wire 2219
- Weld strength (typ.) .... Heat treated after weld
- T_{uw} .... 435 N/mm^2
- T_{yw} .... 335 N/mm^2
- Elong 10%

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet & Plate	T62	0.50-50	370	250	6	38	310		820	615	
	T81	0.50-6.0	430	320	6	470	350		930	755	
	T851	6.0-50	410	300	5	430	350		930	755	
	T87	0.50- 00	440	360	6	500	370		970	815	
Extrusion	T8511	0.50-75	400	290	6	410					
Forging	T6	≤100	400	280	4						
	T852	≤100	430	340	3						

* Properties of Alloy 2219 have been changed to comply with most recent specifications.

Application: Military Bridges

Designation: DGFVE 232B

Country: UK

Availability:

- Sheet .... Available
- Plate .... Available
- Shapes (Ext.)... Available
- Tube .... Available
- Bar .... Available
- Forgings .... Available

Relative Fabrication Rating:
(See paragraph A.2)

- Cold Working - O ...... a
- Cold Working - T c
- Arc Welding .... a
- Resistance Welding .... a
- Brazing .... b
- Machining .... b

Chemical Composition:

Element	%
Si	0.2 max
Fe	0.3 max
Cu	0.12-0.16
Mn	0.15-0.35
Mg	1.8-2.2
Cr	0.05 max
Zn	3.7-4.2
Ti	0.1 max
Zr	0.1-0.25
Others, ea	0.15 max
Others, Total	0.15 max
Al	Remainder

Properties:

- Density .... 2,800 kg/m^3
- Spec Gravity ... 2.8
- Thermal Exp .. 23.8 x 10^{-6}/K
- Mod of Elas .... 71 x 10^3 N/mm^2
- Mod of Rid ..... 27.7 x 10^3 N/mm^2
- K_{IC}................. 32 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph A.2)

- General .... b
- Stress Corrosion .... b

National Specifications:

Specification DGFVE 232.4

Joinings:

- Rivet alloys .... --
- Welding wire NG61
- Weld strength (typ.) .... Naturally aged failure in Heat Affected Zone (HAZ).
- T_{uw} .... 310 N/mm^2
- T_{yw} .... 215 N/mm^2
- Elong 5%

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)								Brinnell No.
			Tension (L)			Comp (L)	Shear		Bearing		
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet, Plate & Extrusion	TF		385	330	8				820	616	

Application: Armor Plate

Designation: MVEE 1318B

Country: UK

Availability:
- Sheet .... Not Available
- Plate .... Available >6.3 mm
- Shapes (Ext.)... Available (MVEE 517)
- Tube .... --
- Bar .... --
- Forgings .... Available

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... --
- Cold Working - T .... --
- Arc Welding .... b
- Resistance Welding .... b
- Brazing .... --
- Machining .... b

Chemical Composition:

Element	%
Si	0.3 max
Fe	0.4 max
Cu	0.25 max
Mn	0.1-0.7
Mg	1.7-3.3
Cr	0.25 max
Zn	4.0-6.0
Zr	0.25 max
Others, ea	--
Others, Total	--
Al	Remainder

Properties:
- Density .... 2,800 kg/m^3
- Spec Gravity ... 2.8
- Thermal Exp .. 23.8 x 10^{-6}/K
- Mod of Elas .... 71 x 10^3 N/mm^2
- Mod of Rid ..... 27 x 10^3 N/mm^2
- K_{IC}................. 30 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph A.2)
- General .... b
- Stress Corrosion .... b-

National Specifications:
Proprietary alloy

Joinings:
- Rivet alloys .... --
- Welding wire NG61
- Weld strength (typ.) .... Welds naturally aged
- T_{uw} .... 350 N/mm^2
- T_{yw} .... 290 N/mm^2
- Elong 5%

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2) Tension (L) F_{tu}	F_{ty}	Elong.(%)	Comp (L) F_{cy}	Shear F_{su}	F_{sy}	Bearing F_{bru}	F_{bry}	Brinnell No.
Plate		6-<51	430	360	8						
		51-<76	410	340	8						
		>76	410	340	6						
Extrusion	TF	≤6	430	410	8						
		6-100	465	425	8						
Forging	TF		385	315	7						

Application:
Welded structures, military bridges

Designation:
7005

Country:
US

Availability:
- Sheet T63, T6351
- Plate T63, T6351
- Shapes (Ext.)... T53
- Tube .... --
- Bar .... --
- Forgings T53

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T c
- Arc Welding .... a
- Resistance Welding .... a
- Brazing .... --
- Machining .... b

Chemical Composition:

Element	%
Si	0.35 max
Fe	0.40 max
Cu	0.10 max
Mn	0.20-0.70
Mg	1.0-1.8
Cr	0.06-0.20
Zn	4.0-5.0
Zr	0.08-0.20
Ti	0.01-0.06
Others, ea	0.05 max
Others, Total	0.15 max
Al	Remainder

Properties:
- Density .... 2,800 kg/m^3
- Spec Gravity ... 2.80
- Thermal Exp .. 23.8 x 10^{-6}/K
- Mod of Elas .... 71 x 10^3 N/mm^2
- Mod of Rid ..... 27 x 10^3 N/mm^2
- K_{IC}.................. 55 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph A.2)
- General .... b
- Stress Corrosion .... b

National Specifications:
ASTM B 221-90

Joinings:
- Rivet alloys 1100, 6053-T61
- Welding wire 5356, 5039
- Weld strength (typ.) .... Naturally aged
- T_{uw} .... 300 N/mm^2
- T_{yw} .... 200 N/mm^2
- Elong 9%

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)								Brinnell No.
			Tension (L)			Comp (L)	Shear		Bearing		
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Extrusion	T53	All	350	310	10	310	190		495	405	
Sheet & Plate	T63	6-75	325	260	7	325	180		480	365	

Application:
Military bridges, amphibious vehicles (M2 Beaver)

Designation:
AlZnMg1 3 x 4335

Country:
FRG

Availability:
- Sheet .... 3 x 4335 x 20
- Plate .... 3 x 4335 x 20
- Shapes (Ext.)... 3 x 4335 x 71
- Tube .... 3 x 4335 x 08
- Bar .... 3 x 4335 x 10
- Forgings .... 3 x 4335 x 61

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T .... d
- Arc Welding .... b
- Resistance Welding .... b
- Brazing .... --
- Machining .... b

Chemical Composition:

Element	%
Si	0.5 max
Fe	0.5 max
Mn	0.1-0.5
Mg	1.0-1.4
Cr	0.1-2.5
Zn	4.0-5.0
Zr	0.1-0.2
Others, ea	--
Others, Total	--
Al	Remainder

Properties:
- Density .... 2,770 kg/m^3
- Spec Gravity ... --
- Thermal Exp .. 24.1 x 10^{-6}/K
- Mod of Elas .... 70.5 x 10^3 N/mm^2
- Mod of Rid ..... 27.5 x 10^3 N/mm^2
- K_{IC}................. 30 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph A.2)
- General .... b
- Stress Corrosion .... b

National Specifications:
Military technical specifications are in preparation.

Joinings:*
- Rivet alloys .... 3 x 3556
- Welding wire .... 3 x 3548, 3 x 3556
- Weld strength (typ.) ...... Heat treated after weld
- T_{uw} .... 275 N/mm^2
- T_{yw} .... 216 N/mm^2
- Elong .... --

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet	0.20	0.0-200	220	110	15	110					450
Plate	0.10	0.3-200	220	110	15	110					450
	0.51	0.3-200	320	220	12	220					700
	0.71	0.3-200	360	280	10	280					800
Shapes	0.71	1.2-15	360	280	10	280					800
Tube	0.08	0.5-30	320	220	12	220					700
	0.71	0.5-30	360	280	12	220					800
Bar	0.51	3.5-79	320	220	12	280					700
	0.51	79-250	320	220	12	220					700
	0.71	50-79	340	290	8	290					750
Forging	0.61		360	280	10	280					800

* Special firms are necessary to perform welding work.

Application:
Future military bridges, amphibious vehicles*

Designation:
AlZnMg2

Country:
FRG

Availability:
- Sheet .... Available
- Plate .... Available
- Shapes (Ext.)... --
- Tube .... --
- Bar .... --
- Forgings .... --

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T .... d
- Arc Welding .... b
- Resistance Welding .... b
- Brazing .... --
- Machining .... a

Chemical Composition:

Element	%
Si	0.5 max
Fe	0.5 max
Mn	0.1-0.5
Mg	1.5-2.0
Cr	0.1-0.5
Zn	5.5-6.5
Zr	0.1-0.2
Others, ea	--
Others, Total	--
Al	Remainder

Properties:
- Density .... 2,770 kg/m^3
- Spec Gravity ... --
- Thermal Exp .. --
- Mod of Elas .... 70.0 x 10^3 N/mm^2
- Mod of Rid ..... 26.0 x 10^3 N/mm^2
- K_{IC}................. 15 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph A.2)
- General .... --
- Stress Corrosion .... --

National Specifications:
DIN 1725, 1745

Joinings:
- Rivet alloys .... 3 x 3556
- Welding wire .... 3 x 3548, 3 x 3556
- Weld strength (typ.) ...... Heat treated after weld
- T_{uw} .... 304 N/mm^2
- T_{yw} .... 226 N/mm^2
- Elong .... --

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet	--	5-20	320	220	12	220					1,000
		20-100	360	280	10	280					1,000

* The material will be available in the development phase of the Bridges of the Eighties program. Current research is directed towards: (a) High-strength welding wire, (b) Improvement of corrosion resistance, and (c) Improvement of fatigue properties.

Application:
New proposed welded structure

Designation:
x7046

Country:
US

Availability:
- Sheet 0, T63
- Plate 0, T63
- Shapes (Ext.)... --
- Tube .... --
- Bar .... --
- Forgings .... --

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T c
- Arc Welding .... a
- Resistance Welding .... --
- Brazing .... b
- Machining .... --

Chemical Composition:

Element	%
Si	0.40 max
Fe	0.35 max
Cu	0.10 max
Mn	0.30 max
Mg	1.3 max
Cr	0.12 max
Zn	7.0 max
Ti	0.03 max
Zr	0.12 max
Others, ea	--
Others, Total	--
Al	Remainder

Properties:
- Density .... 2,800 kg/m^3
- Spec Gravity ... 2.8
- Thermal Exp .. 23.8 x 10^{-6}/K
- Mod of Elas .... 71 x 10^3 N/mm^2
- Mod of Rid ..... 27 x 10^3 N/mm^2
- K_{IC}................. --

Corrosion Resistance:
(See paragraph A.2)
- General .... a
- Stress Corrosion .... --

National Specifications:
--

Joinings:
- Rivet alloys .... --
- Welding wire 5183
- Weld strength (typ.) .... --
- T_{uw} .... --
- T_{yw} .... --
- Elong .... --

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)*								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet & Plate	0		180	117	18	117					
	T63		420	375	13	375					

* Typical properties.

Application:
Aircraft and high-strength nonweldable applications

Designation:
7075

Country:
US

Availability:
- Sheet 0, T6, T73
- Plate 0, T6, T73
- Shapes (Ext.)... 0, T6, T73
- Tube 0, T6, T73
- Bar 0, T6, T651
- Forgings 0, T6, T73

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T .... d
- Arc Welding .... c, d
- Resistance Welding .... b
- Brazing X
- Machining .... b

Chemical Composition:

Element	%
Si	0.40 max
Fe	0.50 max
Cu	1.2-2.0
Mn	0.30 max
Mg	2.1-2.9
Cr	0.18-0.28
Zn	5.1-6.1
Ti	0.20 max
Others, ea	0.05 max
Others, Total	0.15 max
Al	Remainder

Properties:
- Density .... 2,800 kg/m^3
- Spec Gravity ... 2.8
- Thermal Exp .. 23.8 x 10^{-6}/K
- Mod of Elas .... 71 x 10^3 N/mm^2
- Mod of Rid ..... 27 x 10^3 N/mm^2
- K_{IC}.................. 32 $MN/m^{3/2}$

Corrosion Resistance:
(See paragraph A.2)
- General c
- Stress Corrosion .... c, b

National Specifications:
- ASTM B209
- ASTM B221
- ASTM B241

Joinings:
- Rivet alloys 6061, 2117, 2017,2024
- Welding wire .... --
- Weld strength (typ.) .... (Not recommended)
- T_{uw} .... --
- T_{yw} .... --
- Elong .... --

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet & Plate	0	40-50	275	145	10	145	185	68	600	285	60
	T6	1-50	530	460	6	530					150
	T73	1-6	460	385	8	385					
Extrusion	0	All	275	165	10	165					
	T6	0.50-50	558	490	7	490					
	T73	1.5-50	470	400	7	400					
Forging	T6	≤50	500	420	9(L)/4(T)	420					
	T73	≤50	440	370	7(L)/4(T)	370					

Application:
Unspecified

Designation:
7020

Country:
UK

Availability:
- Sheet .... Available
- Plate .... Available
- Shapes (Ext.)... Available
- Tube .... Available
- Bar .... Available
- Forgings .... Available

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T c
- Arc Welding .... a
- Resistance Welding .... a
- Brazing .... b
- Machining .... b

Chemical Composition:

Element	%
Si	0.35 max
Fe	0.40 max
Cu	0.2 max
Mn	0.05-0.5
Mg	1.0-1.4
Cr	0.1-0.35
Zn	4.0-5.0
Zr	0.08-0.2
Ti	0.1 max
Zr + Ti	0.08-0.25
Others, ea	--
Others, Total	--
Al	Remainder

Properties:
- Density .... 2,800 kg/m^3
- Spec Gravity ... 2.8
- Thermal Exp .. Expected to be
- Mod of Elas .... within 5% of
- Mod of Rid ..... values obtained
- K_{IC}.................. for Al 7005

Corrosion Resistance:
(See paragraph A.2)
- General .... b
- Stress Corrosion .... b

National Specifications:
--

Joinings:
- Rivet alloys .... --
- Welding wire NG61
- Weld strength (typ.) ...... Naturally aged
- T_{uw} .... 300 N/mm^2
- T_{yw} .... 200 N/mm^2
- Elong 5%

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2)*								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet, Plate & Extrusion	TF		320	270	8						

* Above are minimum tensile properties expected from any thickness of any wrought form. Typical values of 12-25 mm (0.5-1.0 in) thick plates or extrusions are likely to be some 50 MPa (5.1x10^6 kp/m^2, 7,250 lbs/in^2) above these values.

Application:
Military bridges, upgrades

Designation:
7050

Country:
US

Availability:
- Sheet .... Clad
- Plate T7651, T7451, T73651
- Shapes (Ext.)... T76511, T73511
- Tube .... Not Available
- Bar .... Not Available
- Forgings T7452, T74, T73652

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O ...... b
- Cold Working - T .... b
- Arc Welding .... d
- Resistance Welding .... b
- Brazing .... d
- Machining .... b

Chemical Composition:

Element	%
Si	0.12 max
Fe	0.15 max
Cu	2.0-2.6
Mn	0.10 max
Mg	1.9-2.6
Cr	0.04 max
Zn	5.7-6.7
Zr	0.08-0.15
Ti	0.06 max
Others, ea	0.05 max
Others, Total	0.15 max
Al	Remainder

Properties:
- Density .... 2,830 kg/m^3
- Spec Gravity ... --
- Thermal Exp .. 23.0 x 10^{-6}/K
- Mod of Elas .... 70.3 x 10^3 N/mm^2
- Mod of Rid ..... 26.9 x 10^3 N/mm^2
- K_{IC}.................. 45.1 MN/$m^{3/2}$

Corrosion Resistance:
(See paragraph A.2)
- General c
- Stress Corrosion .... b

National Specifications:
AMS 4050A, 4201, 4340,
4342, 4341, 4107, 4108

Joinings:
- Rivet alloys 7050-T73
- Welding wire 5356, 4043
- Weld strength (typ.) .... 50% of parent metal
- T_{uw} .... --
- T_{yw} .... --
- Elong 1%

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Plate	T7651	6-76	524-545	455-483	7-9	441-503	290-324		765-1041	600-758	
	T7451	6-152	483-524	414-462	4-10	393-483	290-310		724-1027	593-745	
Extrusion	T76510	12-127	469-545	407-476	7	455-490	283-303		738-1041	558-765	
	T73510	19-127	427-483	365-414	8	393-421	255-269		634-910	510-655	
Forging	All	50-150	455-496	372-427	3-9	393-441	276-290		662-903	538-696	

Application: Bridge structures, general structures	**Designation:** St-52-3 **Country:** FRG

Availability:
- Sheet .... Available
- Plate .... Available
- Shapes (Ext.)... Available
- Tube .... Available
- Bar .... Available
- Forgings .... Available

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T .... a
- Arc Welding .... a
- Resistance Welding .... a
- Brazing .... a
- Machining .... a

Chemical Composition:

Element	%
C	0.20 max
P	0.05 max
S	0.05 max
N	0.04 max
Others, ea	--
Others, Total	--
Fe	Remainder

Properties:
- Density .... 7,850 kg/m^3
- Spec Gravity ... --
- Thermal Exp .. 12.0 x 10^{-6}/K
- Mod of Elas .... 204 x 10^3 N/mm^2
- Mod of Rid ..... 79.5 x 10^3 N/mm^2
- K_{IC}.................. --

Corrosion Resistance:
(See paragraph A.2)
- General .... d
- Stress Corrosion .... a

National Specifications:
--

Joinings:
- Rivet alloys .... MRSt 44
- Welding wire .... St 52
- Weld strength (typ.) .... No heat treatment
- T_{uw} .... 510 N/mm^2
- T_{yw} .... 353 N/mm^2
- Elong .... --

Form	**Temper**	**Thickness**	**Minimum Mechanical Properties (N/mm^2)***								Brinnell No.
			Tension (L)			Comp (L)	Shear		Bearing		
		(mm)	F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
All	RR	5-16	520	360	22	360					1,450
		16-40	520	350	22	350					1,450
		40-100	520	340	22	340					1,450

* The ratio of strength to density is hardly satisfactory for military bridges. Maraging steels have better values for static strength, but there are difficulties regarding fatigue behavior and ductility.

Application:
High-strength, welded construction equipment and machinery

Designation:
T-1 Steel

Country:
US

Availability:
- Sheet .... --
- Plate .... Available
- Shapes (Ext.)... --
- Tube .... Available
- Bar .... Available
- Forgings .... --

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T .... a
- Arc Welding .... a
- Resistance Welding .... a
- Brazing .... a
- Machining .... a

Chemical Composition:

Element	%
C	0.10-0.20
Ni	0.60-1.0
Mo	0.40-0.60
Mn	0.60-1.0
Cr	0.40-0.65
Si	0.20-0.35
V	0.03-0.08
Cu	0.015-0.50
Others, ea	0.04 max
Others, Total	1.0 max
Fe	Remainder

Properties:
- Density .... 8,000 kg/m^3
- Spec Gravity ... 8.0
- Thermal Exp .. 13.9×10^{-6}/K
- Mod of Elas .... 210×10^3 N/mm^2
- Mod of Rid ..... --
- K_{IC}.................. --

Corrosion Resistance:
(See paragraph A.2)
- General .... d
- Stress Corrosion .... a

National Specifications:
ASTM-A-514

Joinings:
- Rivet alloys .... --
- Welding wire .... Low-hydrogen rod (E120)
- Weld strength (typ.) .... Typical
- T_{uw} .... 730 N/mm^2
- T_{yw} .... 630 N/mm^2
- Elong 11%

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			F_{tu}	F_{ty}	Elong.(%) *	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet & Plate		5-64	800	700	18	700	600	400			321
		64-150	730	630	17	630	550	360			

* Elongations are given for 50.8 mm (2.0 in) gage length.

Application:
Aircraft components, mechanism parts

Designation:
18% Maraging

Country:
US & UK

Availability:
- Sheet .... Available
- Plate .... Available
- Shapes (Ext.)... --
- Tube .... --
- Bar .... --
- Forgings .... Available

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T X
- Arc Welding .... a
- Resistance Welding .... a
- Brazing .... --
- Machining .... d

Chemical Composition:

Element	%
C	0.02 max
Ni	18.5 max
Co	8.5 max
Mo	4.8 max
Mn	0.3 max
Ti	0.25 max
Si	0.01 max
Al	0.20 max
Others, ea	0.04 max
Others, Total	1.0 max
Fe	Remainder

Properties:
- Density .... 8,000 kg/m^3
- Spec Gravity ... --
- Thermal Exp .. 10.0 x 10^{-6}/K
- Mod of Elas .... 189 x 10^3 N/mm^2
- Mod of Rid ..... 72.9 x 10^3 N/mm^2
- K_{IC}................. 110 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph A.2)
- General .... d
- Stress Corrosion .... d

National Specifications:
--

Joinings:
- Rivet alloys .... --
- Welding wire .... Same as base metal
- Weld strength (typ.) .... Equal to parent metal after aging 3 hr @ 48 °C (118 °F)
- T_{uw} .... 1,410 N/mm^2
- T_{yw} .... 1,350 N/mm^2
- Elong .... 10% or 50 mm

Form	Temper	Thickness	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
		(mm)	F_{tu}*	F_{ty}	Elong.(%) †	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Sheet & Plate		1.5-6	1,460	1,390	4	1,390					43
		6-11	1,460	1,390	15	1,390					43

* Maraging steel is available in higher strengths (up to 2,500 N/mm^2, 255x10^6 kp/m^2, 362x10^3 lbs/in^2) in special orders.

† Elongations are given for a gage length of $4.5\sqrt{A}$ where A is the cross-sectional area in square inches.

Application:
Pins, hinges, hydraulic pressure vessels, mechanism linkages

Designation:
4340

Country:
US

Availability:
- Sheet .... --
- Plate .... Available
- Shapes (Ext.)... --
- Tube .... Available
- Bar .... Available
- Forgings .... Available

Relative Fabrication Rating:
(See paragraph A.2)
- Cold Working - O .... a
- Cold Working - T .... --
- Arc Welding .... *
- Resistance Welding .... *
- Brazing .... --
- Machining .... a

Chemical Composition:

Element	%
C	0.38-0.43
Cr	0.70-0.90
Ni	1.65-2.00
P	0.04 max
Mo	0.20-0.30
Mn	0.60-0.85
S	0.15-0.35
Si	0.20-0.35
Others, ea	--
Others, Total	--
Fe	Remainder

Properties:
- Density .... 8,000 kg/m^3
- Spec Gravity ... 8.0
- Thermal Exp .. --
- Mod of Elas .... 200 x 10^3 N/mm^2
- Mod of Rid ..... 76 x 10^3 N/mm^2
- K_{IC}.................. --

Corrosion Resistance:
(See paragraph A.2)
- General .... d
- Stress Corrosion .... a

National Specifications:
ASTM A320/A, 320M-88

Joinings:
- Rivet alloys .... --
- Welding wire 4340
- Weld strength (typ.) .... Same as parent material after heat treatment.
- T_{uw} .... --
- T_{yw} .... --
- Elong .... --

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2) Tension (L) F_{tu}	Tension (L) F_{ty}	Tension (L) Elong.(%)	Comp (L) F_{cy}	Shear F_{su}	Shear F_{sy}	Bearing F_{bru}	Bearing F_{bry}	Brinnell No.
All		5-15	1,800 760	1,480 482	10 22	1,650 482	1,070				510 290

* 4340 can be welded only with special care.

APPENDIX B

CONVERSION FACTORS

B-1 LENGTH

TO TO CONVERT	in	ft	mi	mm	cm	m	km
	MULTIPLY BY						
in	1.000e+00	8.333e-02	1.578e-05	2.540e+01	2.540e+00	2.540e-02	2.540e-05
ft	1.200e+01	1.000e+00	1.894e-04	3.048e+02	3.048e+01	3.048e-01	3.048e-04
mi	6.336e+04	5.280e+03	1.000e+00	1.609e+06	1.609e+05	1.609e+03	1.609e+00
mm	3.937e-02	3.281e-03	6.214e-07	1.000e+00	1.000e-01	1.000e-03	1.000e-06
cm	3.937e-01	3.281e-02	6.214e-06	1.000e+01	1.000e+00	1.000e-02	1.000e-05
m	3.937e+01	3.281e+00	6.214e-04	1.000e+03	1.000e+02	1.000e+00	1.000e-03
km	3.937e+04	3.281e+03	6.214e-01	1.000e+06	1.000e+05	1.000e+03	1.000e+00

B-2 AREA

TO TO CONVERT	in^2	ft^2	mm^2	cm^2	m^2
	MULTIPLY BY				
in^2	1.000e+00	6.944e-03	6.452e+02	6.452e+00	6.452e-04
ft^2	1.440e+02	1.000e+00	9.290e+04	9.290e+02	9.290e-02
mm^2	1.550e-03	1.076e-05	1.000e+00	1.000e-02	1.000e-06
cm^2	1.550e-01	1.076e-03	1.000e+02	1.000e+00	1.000e-04
m^2	1.550e+03	1.076e+01	1.000e+06	1.000e+04	1.000e+00

B-3 VOLUME

TO TO CONVERT	in^3	ft^3	mm^3	cm^3	m^3
	MULTIPLY BY				
in^3	1.000e+00	5.787e-04	1.639e+04	1.639e+01	1.639e-05
ft^3	1.728e+03	1.000e+00	2.832e+07	2.832e+04	2.832e-02
mm^3	6.102e-05	3.532e-08	1.000e+00	1.000e-03	1.000e-09
cm^3	6.102e-02	3.532e-05	1.000e+03	1.000e+00	1.000e-06
m^3	6.102e+04	3.532e+01	1.000e+09	1.000e+06	1.000e+00

B-4 WEIGHT AND FORCE

TO	lb	kip	Ton(S)	Ton(L)	kg (kp)	Mp (Tonne)	N	kN	MN
TO CONVERT	**MULTIPLY BY**								
lb	1.000e+00	1.000e-03	5.000e-04	4.465e-04	4.536e-01	4.536e-04	4.448e+00	4.448e-03	4.448e-06
kip	1.000e+03	1.000e+00	5.000e-01	4.465e-01	4.536e+02	4.536e-01	4.448e+03	4.448e+00	4.448e-03
Ton(S)	2.000e+03	2.000e+00	1.000e+00	8.930e-01	9.072e+02	9.072e-01	8.896e+03	8.896e+00	8.896e-03
Ton(L)	2.240e+03	2.240e+00	1.120e+00	1.000e+00	1.016e+03	1.016e+00	9.962e+03	9.962e+00	9.962e-03
kg (kp)	2.205e+00	2.205e-03	1.102e-03	9.843e-04	1.000e+00	1.000e-03	9.806e+00	9.806e-03	9.806e-06
Mp (Tonne)	2.205e+03	2.205e+00	1.102e+00	9.843e-01	1.000e+03	1.000e+00	9.806e+03	9.806e+00	9.806e-03
N	2.248e-01	2.248e-04	1.124e-04	1.004e-04	1.020e-01	1.020e-04	1.000e+00	1.000e-03	1.000e-06
kN	2.248e+02	2.248e-01	1.124e-01	1.004e-01	1.020e+02	1.020e-01	1.000e+03	1.000e+00	1.000e-03
MN	2.248e+05	2.248e+02	1.124e+02	1.004e+02	1.020e+05	1.020e+02	1.000e+06	1.000e+03	1.000e+00

B-5 VELOCITY

TO	ft/s	ft/min	mi/h	knot	m/s	km/h
TO CONVERT	**MULTIPLY BY**					
ft/s	1.000e+00	6.000e+01	6.818e-01	5.925e-01	3.048e-01	1.097e+00
ft/min	1.667e-02	1.000e+00	1.136e-02	9.875e-03	5.080e-03	1.829e-02
mi/h	1.467e+00	8.800e+01	1.000e+00	8.690e-01	4.471e-01	1.609e+00
knot	1.688e+00	1.013e+02	1.151e+00	1.000e+00	5.144e-01	1.852e+00
m/s	3.281e+00	1.969e+02	2.237e+00	1.944e+00	1.000e+00	3.600e+00
km/h	9.113e-01	5.468e+01	6.214e-01	5.400e-01	2.778e-01	1.000e+00

B-6 $\frac{\text{WEIGHT OR FORCE}}{\text{LENGTH}}$

TO	lb/ft	kg/m (kp/m)	kN/m
TO CONVERT	**MULTIPLY BY**		
lb/ft	1.000e+00	1.488e+00	1.459e-02
kg/m (kp/m)	6.722e-01	1.000e+00	9.806e-03
kN/m	6.853e+01	1.020e+02	1.000e+00

B-7 DENSITY

TO	lb/in^3	lb/ft^3	kg/cm^3 (kp/cm^3)	kg/m^3 (kp/m^3)
TO CONVERT	**MULTIPLY BY**			
lb/in^3	1.000e+00	1.728e+03	2.768e-02	2.768e+04
lb/ft^3	5.786e-04	1.000e+00	1.602e-05	1.602e+01
kg/cm^3 (kp/cm^3)	3.613e+01	6.243e+04	1.000e+00	1.000e+06
kg/m^3 (kp/m^3)	3.613e-05	6.243e-02	1.000e-06	1.000e+00

B-8.1 PRESSURE OR STRESS

TO	lb/in^2	lb/ft^2	kip/in^2	kip/ft^2	Ton(S)/in^2	Ton(S)/ft^2	Ton(L)/in^2	Ton(L)/ft^2	kg/cm^2 (kp/cm^2)
TO CONVERT	**MULTIPLY BY**								
lb/in^2	1.000e+00	1.440e+02	1.000e-03	1.440e-01	5.000e-04	7.201e-02	4.465e-04	6.430e-02	7.031e-02
lb/ft^2	6.944e-03	1.000e+00	6.944e-06	1.000e-03	3.472e-06	5.000e-04	3.100e-06	4.465e-04	4.882e-04
kip/in^2	1.000e+03	1.440e+05	1.000e+00	1.440e+02	5.000e-01	7.201e+01	4.465e-01	6.430e+01	7.031e+01
kip/ft^2	6.944e+00	1.000e+03	6.944e-03	1.000e+00	3.472e-03	5.000e-01	3.100e-03	4.465e-01	4.882e-01
Ton(S)/in^2	2.000e+03	2.880e+05	2.000e+00	2.880e+02	1.000e+00	1.440e+02	8.930e-01	1.286e+02	1.406e+02
Ton(S)/ft^2	1.389e+01	2.000e+03	1.389e-02	2.000e+00	6.944e-03	1.000e+00	6.201e-03	8.930e-01	9.764e-01
Ton(L)/in^2	2.240e+03	3.225e+05	2.240e+00	3.225e+02	1.120e+00	1.613e+02	1.000e+00	1.440e+02	1.575e+02
Ton(L)/ft^2	1.555e+01	2.240e+03	1.555e-02	2.240e+00	7.776e-03	1.120e+00	6.944e-03	1.000e+00	1.093e+00
kg/cm^2 (kp/cm^2)	1.422e+01	2.048e+03	1.422e-02	2.048e+00	7.112e-03	1.024e+00	6.351e-03	9.146e-01	1.000e+00
kg/m^2 (kp/m^2)	1.422e-03	2.048e-01	1.422e-06	2.048e-04	7.112e-07	1.024e-04	6.351e-07	9.146e-05	1.000e-04
Mp/cm^2	1.422e+04	2.048e+06	1.422e+01	2.048e+03	7.112e+00	1.024e+03	6.351e+00	9.146e+02	1.000e+03
Mp/m^2	1.422e+00	2.048e+02	1.422e-03	2.048e-01	7.112e-04	1.024e-01	6.351e-04	9.146e-02	1.000e-01
N/mm^2 (MPa)	1.450e+02	2.089e+04	1.450e-01	2.089e+01	7.252e-02	1.044e+01	6.476e-02	9.327e+00	1.020e+01
N/m^2 (Pa)	1.450e-04	2.089e-02	1.450e-07	2.089e-05	7.252e-08	1.044e-05	6.476e-08	9.327e-06	1.020e-05
kN/mm^2	1.450e+05	2.089e+07	1.450e+02	2.089e+04	7.252e+01	1.044e+04	6.476e+01	9.327e+03	1.020e+04
kN/m^2	1.450e-01	2.089e+01	1.450e-04	2.089e-02	7.252e-05	1.044e-02	6.476e-05	9.327e-03	1.020e-02
MN/mm^2	1.450e+08	2.089e+10	1.450e+05	2.089e+07	7.252e+04	1.044e+07	6.476e+04	9.327e+06	1.020e+07
MN/m^2 (MPa)	1.450e+02	2.089e+04	1.450e-01	2.089e+01	7.252e-02	1.044e+01	6.476e-02	9.327e+00	1.020e+01

B-8.2 PRESSURE OR STRESS

TO	kg/m^2 (kp/m^2)	Mp/cm^2	Mp/m^2	N/mm^2 (MPa)	N/m^2 (Pa)	kN/mm^2	kN/m^2	MN/mm^2	MN/m^2 (MPa)
TO CONVERT	**MULTIPLY BY**								
lb/in^2	7.031e+02	7.031e-05	7.031e-01	6.894e-03	6.894e+03	6.894e-06	6.894e+00	6.894e-09	6.894e-03
lb/ft^2	4.882e+00	4.882e-07	4.882e-03	4.787e-05	4.787e+01	4.787e-08	4.787e-02	4.787e-11	4.787e-05
kip/in^2	7.031e+05	7.031e-02	7.031e+02	6.894e+00	6.894e+06	6.894e-03	6.894e+03	6.894e-06	6.894e+00
kip/ft^2	4.882e+03	4.882e-04	4.882e+00	4.787e-02	4.787e+04	4.787e-05	4.787e+01	4.787e-08	4.787e-02
Ton(S)/in^2	1.406e+06	1.406e-01	1.406e+03	1.379e+01	1.379e+07	1.379e-02	1.379e+04	1.379e-05	1.379e+01
Ton(S)/ft^2	9.764e+03	9.764e-04	9.764e+00	9.575e-02	9.575e+04	9.575e-05	9.575e+01	9.575e-08	9.575e-02
Ton(L)/in^2	1.575e+06	1.575e-01	1.575e+03	1.544e+01	1.544e+07	1.544e-02	1.544e+04	1.544e-05	1.544e+01
Ton(L)/ft^2	1.093e+04	1.093e-03	1.093e+01	1.072e-01	1.072e+05	1.072e-04	1.072e+02	1.072e-07	1.072e-01
kg/cm^2 (kp/cm^2)	1.000e+04	1.000e-03	1.000e+01	9.806e-02	9.806e+04	9.806e-05	9.806e+01	9.806e-08	9.806e-02
kg/m^2 (kp/m^2)	1.000e+00	1.000e-07	1.000e-03	9.806e-06	9.806e+00	9.806e-09	9.806e-03	9.806e-12	9.806e-06
Mp/cm^2	1.000e+07	1.000e+00	1.000e+04	9.806e+01	9.806e+07	9.806e-02	9.806e+04	9.806e-05	9.806e+01
Mp/m^2	1.000e+03	1.000e-04	1.000e+00	9.806e-03	9.806e+03	9.806e-06	9.806e+00	9.806e-09	9.806e-03
N/mm^2 (MPa)	1.020e+05	1.020e-02	1.020e+02	1.000e+00	1.000e+06	1.000e-03	1.000e+03	1.000e-06	1.000e+00
N/m^2 (Pa)	1.020e-01	1.020e-08	1.020e-04	1.000e-06	1.000e+00	1.000e-09	1.000e-03	1.000e-12	1.000e-06
kN/mm^2	1.020e+08	1.020e+01	1.020e+05	1.000e+03	1.000e+09	1.000e+00	1.000e+06	1.000e-03	1.000e+03
kN/m^2	1.020e+02	1.020e-05	1.020e-01	1.000e-03	1.000e+03	1.000e-06	1.000e+00	1.000e-09	1.000e-03
MN/mm^2	1.020e+11	1.020e+04	1.020e+08	1.000e+06	1.000e+12	1.000e+03	1.000e+09	1.000e+00	1.000e+06
MN/m^2 (MPa)	1.020e+05	1.020e-02	1.020e+02	1.000e+00	1.000e+06	1.000e-03	1.000e+03	1.000e-06	1.000e+00

B-9 SLOPE

Slope	Angle (Degrees)	Percent (%)
1 in 2	26.57	50.00
1 in 3	18.43	33.33
1 in 4	14.04	25.00
1 in 5	11.31	20.00
1 in 6	9.46	16.67
1 in 7	8.13	14.29
1 in 8	7.13	12.50
1 in 9	6.34	11.11
1 in 10	5.71	10.00
1 in 11	5.19	9.09
1 in 12	4.76	8.33
1 in 13	4.40	7.69
1 in 14	4.09	7.14
1 in 15	3.81	6.67
1 in 16	3.58	6.25
1 in 17	3.37	5.88
1 in 18	3.18	5.56
1 in 19	3.01	5.26
1 in 20	2.86	5.00

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C-1.1

HYPOTHETICAL VEHICLES FOR MILITARY LOAD CLASSES (METRIC)

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	TRACKED VEHICLES	AXLE LOADS AND SPACING	MAXIMUM SINGLE AXLE LOAD	MINIMUM WHEEL SPACING AND TIRE SIZES (mm) OF CRITICAL AXLES			MAX. TIRE LOAD AND MIN. TIRE SIZE (mm)
4	30 Tons 18” 11’ 100”	4.08 Tonnes 1.22 2.44 1.59 1.59 0.91	2.27	Single Axle: 191 x 508 1.83 Bogie Axle: 191 x 508	Single Axle: 152 x 508 0.36 0.36 1.83 Bogie Axle: 152 x 406	Note: Spacing between center tires ‘x’ equals tire width.	1.13 Tonnes on 191 x 508
8	7.26 Tonnes 0.30 1.98 1.98	8.16 Tonnes 1.22 3.05 2.72 2.72 2.72	4.99	Single Axle: 305 x 508 2.08 Bogie Axle: 229 x 508	Single Axle: 210 x 508 0.48 0.46 2.08 Bogie Axle: 191 x 508		2.49 Tonnes on 305 x 508
12	50 Tons 26” 13’ 128”	13.61 Tonnes 3.66 1.22 3.05 1.81 4.54 4.54 2.72	20.0	Single Axle: 24.00 x 29 112” Bogie Axle: 21.00 x 24	Single Axle: 16.00 x 24 37” 32” 112” Bogie Axle: 14.00 x 20		3.63 Tonnes on 356 x 508
16	60 Tons 28” 14’ 132”	70 Tons 4’ 15’ 5’ 12’ 13.0 13.0 18.0 18.0 8.0	23.0	Single Axle: 407 x 610 2.29 Bogie Axle: 356 x 508	Single Axle: 18.00 x 24 41” 37” 128” Bogie Axle: 16.00 x 24	Single Axle: 18.00 x 24 x 128” Bogie Axle: 16.00 x 24	4.54 Tonnes on 406 x 610
20	70 Tons 31” 15’ 138”	21.77 Tonnes 3.66 1.22 3.05 2.72 7.71 7.71 3.63	25.5	Single Axle: 457 x 610 2.44 Bogie Axle: 356 x 610	Single Axle: 18.00 x 24 41” 37” 132” Bogie Axle: 16.00 x 24	Single Axle: 18.00 x 24 x 132” Bogie Axle: 16.00 x 24	4.99 Tonnes on 457 x 610
24	80 Tons 33” 16’ 144”	25.40 Tonnes 3.66 1.22 3.05 2.72 9.07 9.07 4.54	28.0	Single Axle: 457 x 610 2.44 Bogie Axle: 406 x 610	Single Axle: 21.00 x 24 49” 41” 138” Bogie Axle: 18.00 x 24	Single Axle: 21.00 x 24 x 138” Bogie Axle: 18.00 x 24	5.44 Tonnes on 457 x 610

Metric Tonnes and Meters

N.B.:
(1) Single axle tire sizes shown in Columns 5,6, and 7 refer to the maximum single axle loads given in Column 4.
(2) Bogie axle tire sizes shown in Columns 5,6, and 7 refer to the maximum bogie axle loads shown on the diagram in Column 3.
(3) The maximum tire pressure for all tires shown in Column 8 shall be taken as 690 kN/m^2 (70 kp/cm^2, 100 lbs/in^2).
Actual contact pressures will depend on tire tread pattern and may be as high as 1100 kN/m^2 (112 kp/cm^2, 160 lbs/in^2).
(4) First value of tire size refers to nominal overall width of the tire and the second value refers to the rim diameter, both in millimeters.

APPENDIX C-1.2

HYPOTHETICAL VEHICLES FOR MILITARY LOAD CLASSES (METRIC)

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	**TRACKED VEHICLES**	**AXLE LOADS AND SPACING**	**MAXIMUM SINGLE AXLE LOAD**	**MINIMUM WHEEL SPACING AND TIRE SIZES (mm) OF CRITICAL AXLES**			**MAX. TIRE LOAD AND MIN. TIRE SIZE (mm)**
30	27.72 Tonnes 3.35 0.46 2.54	30.84 Tonnes 3.66 – 1.22 – 3.05 5.44 9.98 9.98 5.44	12.25	Single Axle: 457 x 610 2.44 Bogie Axle: 406 x 610	Single Axle: 356 x 508 0.81 0.66 2.44 Bogie Axle: 305 x 508	Single Axle: 356 x 508 x 2.44 Bogie Axle: 305 x 508	6.12 Tonnes on 457 x 610
40	36.29 Tonnes 3.66 0.56 2.94	42.64 Tonnes 4.88 – 1.22 – 3.66 12.70 11.79 11.79 6.35	15.42	Single Axle: 533 x 610 2.54 Bogie Axle: 457 x 610	Single Axle: 356 x 610 0.81 0.81 2.54 Bogie Axle: 356 x 508	Single Axle: 356 x 610 x 2.54 Bogie Axle: 356 x 508	7.71 Tonnes on 535 x 610
50	45.36 Tonnes 3.96 0.66 3.25	52.62 Tonnes 4.88 – 1.22 – 3.66 18.14 13.61 13.61 7.26	18.14	Single Axle: 610 x 737 2.84 Bogie Axle: 533 x 610	Single Axle: 406 x 610 0.94 0.81 2.84 Bogie Axle: 356 x 508	Single Axle: 406 x 610 x 2.84 Bogie Axle: 356 x 508	9.07 Tonnes on 610 x 737
60	54.43 Tonnes 4.27 0.71 3.35	63.50 Tonnes 1.22 – 4.57 – 1.52 – 3.66 11.79 11.79 16.33 16.33 7.26	20.86		Single Axle: 457 x 610 1.04 0.94 3.25 Bogie Axle: 406 x 610	Single Axle: 457 x 610 x 3.25 Bogie Axle: 406 x 610	9.07 Tonnes on 610 x 737
70	63.50 Tonnes 4.57 0.79 3.51	73.03 Tonnes 1.22 – 4.57 – 1.52 – 3.66 12.70 12.70 19.05 19.05 9.52	23.13		Single Axle: 457 x 610 1.04 0.94 3.35 Bogie Axle: 406 x 610	Single Axle: 457 x 610 x 3.35 Bogie Axle: 406 x 610	9.07 Tonnes on 610 x 737
80	72.58 Tonnes 4.88 0.84 3.66	83.46 Tonnes 1.52 – 5.49 – 1.52 – 3.66 14.51 14.51 21.77 21.77 10.89	25.40		Single Axle: 535 x 610 1.24 1.04 3.51 Bogie Axle: 457 x 610	Single Axle: 535 x 610 x 3.51 Bogie Axle: 457 x 610	9.07 Tonnes on 610 x 737

Metric Tonnes and Meters

N.B.:
(1) Single axle tire sizes shown in Columns 5,6, and 7 refer to the maximum single axle loads given in Column 4.
(2) Bogie axle tire sizes shown in Columns 5,6, and 7 refer to the maximum bogie axle loads shown on the diagram in Column 3.
(3) The maximum tire pressure for all tires shown in Column 8 shall be taken as 690 kN/m^2 (70 kp/cm^2, 100 lbs/in^2).
Actual contact pressures will depend on tire tread pattern and may be as high as 1100 kN/m^2 (112 kp/cm^2, 160 lbs/in^2).
(4) First value of tire size refers to nominal overall width of the tire and the second value refers to the rim diameter, both in millimeters.

APPENDIX C-1.3

HYPOTHETICAL VEHICLES FOR MILITARY LOAD CLASSES (METRIC)

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	TRACKED VEHICLES	AXLE LOADS AND SPACING	MAXIMUM SINGLE AXLE LOAD	MINIMUM WHEEL SPACING AND TIRE SIZES (mm) OF CRITICAL AXLES			MAX. TIRE LOAD AND MIN. TIRE SIZE (mm)
90	30 Tons 18” 11’ 100”	93.89 Tonnes 1.52 5.49 1.52 3.66 16.33 16.33 24.49 24.49 12.25	13.5		Single Axle: 535 x 610 1.24 1.04 3.51 Bogie Axle: 457 x 610	Single Axle: 535 x 610 x 3.51 Bogie Axle: 457 x 610	9.07 Tonnes on 610 x 737
100	40 Tons 22” 12’ 112”	104.33 Tonnes 1.52 6.10 1.83 3.66 18.14 18.14 27.22 27.22 13.61	17.0		Single Axle: 535 x 610 1.24 1.24 3.66 Bogie Axle: 535 x 610	Single Axle: 535 x 610 x 3.66 Bogie Axle: 535 x 610	9.07 Tonnes on 610 x 737
120	50 Tons 26” 13’ 128”	125.19 Tonnes 1.52 6.10 1.83 3.66 21.77 21.77 32.66 32.66 16.33	20.0			x 3.91 Bogie Axle: 610 x 737	20,000 LBS on 24.00 x 29
150	136.36 Tonnes 1.27 7.32 4.67	154.55 Tonnes 1.83 6.71 2.13 3.66 21.77 21.77 32.66 32.66 16.33	38.18			x 4.06 Bogie Axle: 610 x 737	9.55 Tonnes on 610 x 737

Metric Tonnes and Meters

N.B.:
(1) Single axle tire sizes shown in Columns 5,6, and 7 refer to the maximum single axle loads given in Column 4.
(2) Bogie axle tire sizes shown in Columns 5,6, and 7 refer to the maximum bogie axle loads shown on the diagram in Column 3.
(3) The maximum tire pressure for all tires shown in Column 8 shall be taken as 690 kN/m^2 (70 kp/cm^2, 100 lbs/in^2).
Actual contact pressures will depend on tire tread pattern and may be as high as 1100 kN/m^2 (112 kp/cm^2, 160 lbs/in^2).
(4) First value of tire size refers to nominal overall width of the tire and the second value refers to the rim diameter, both in millimeters.

APPENDIX C-2.1

HYPOTHETICAL VEHICLES FOR MILITARY LOAD CLASSES (US CUSTOMARY)

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	TRACKED VEHICLES	AXLE LOADS AND SPACING	MAXIMUM SINGLE AXLE LOAD	MINIMUM WHEEL SPACING AND TIRE SIZES (in) OF CRITICAL AXLES			MAX. TIRE LOAD AND MIN. TIRE SIZE (in)
4	4 Tons 12” 6’ 72”	4.5 Tons 4’ 8’ 1.75 1.75 1.0	2.5	Single Axle: 7.50 x 20 72” Bogie Axle: 7.50 x 20	Single Axle: 6.00 x 20 14” 14” 72” Bogie Axle: 6.00 x 16	Note: Spacing between center tires ‘x’ equals tire width.	2,500 LBS on 7.50 x 20
8	8 Tons 12” 6’-6” 78”	9 Tons 4’ 10’ 3.0 3.0 3.0	5.5	Single Axle: 12.00 x 20 82” Bogie Axle: 9.00 x 20	Single Axle: 8.25 x 20 19” 18” 82” Bogie Axle: 7.50 x 20		5,500 LBS on 12.00 x 20
12	12 Tons 12” 9’ 80”	15 Tons 12’ 4’ 10’ 2.0 5.0 5.0 3.0	8.0	Single Axle: 14.00 x 20 84” Bogie Axle: 9.00 x 20	Single Axle: 10.00 x 20 23” 18” 84” Bogie Axle: 7.50 x 20		8,000 LBS on 14.00 x 20
16	16 Tons 12” 9’ 84”	18.5 Tons 12’ 4’ 10’ 2.5 6.5 6.5 3.0	10.0	Single Axle: 16.00 x 24 90” Bogie Axle: 14.00 x 20	Single Axle: 12.00 x 20 26” 21” 90” Bogie Axle: 9.00 x 20	Single Axle: 12.00 x 20 x 90” Bogie Axle: 9.00 x 20	10,000 LBS on 16.00 x 24
20	20 Tons 16” 9’ 96”	24 Tons 12’ 4’ 10’ 3.0 8.5 8.5 4.0	11.0	Single Axle: 18.00 x 24 96” Bogie Axle: 14.00 x 24	Single Axle: 12.00 x 20 26” 26” 96” Bogie Axle: 12.00 x 20	Single Axle: 12.00 x 20 x 96” Bogie Axle: 12.00 x 20	11,000 LBS on 18.00 x 24
24	24 Tons 18” 9’ 100”	28 Tons 12’ 4’ 10’ 3.0 10.0 10.0 5.0	12.0	Single Axle: 18.00 x 24 96” Bogie Axle: 16.00 x 24	Single Axle: 14.00 x 20 32” 26” 96” Bogie Axle: 12.00 x 20	Single Axle: 14.00 x 20 x 96” Bogie Axle: 12.00 x 20	12,000 LBS on 18.00 x 24

Short Tons and Feet

N.B.:
(1) Single axle tire sizes shown in Columns 5,6, and 7 refer to the maximum single axle loads given in Column 4.
(2) Bogie axle tire sizes shown in Columns 5,6, and 7 refer to the maximum bogie axle loads shown on the diagram in Column 3.
(3) The maximum tire pressure for all tires shown in Column 8 shall be taken as 690 kN/m^2 (70 kp/cm^2, 100 lbs/in^2).
Actual contact pressures will depend on tire tread pattern and may be as high as 1100 kN/m^2 (112 kp/cm^2, 160 lbs/in^2).
(4) First value of tire size refers to nominal overall width of the tire and the second value refers to the rim diameter, both in inches.

APPENDIX C-2.2

HYPOTHETICAL VEHICLES FOR MILITARY LOAD CLASSES (US CUSTOMARY)

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	TRACKED VEHICLES	AXLE LOADS AND SPACING	MAXIMUM SINGLE AXLE LOAD	MINIMUM WHEEL SPACING AND TIRE SIZES (in) OF CRITICAL AXLES			MAX. TIRE LOAD AND MIN. TIRE SIZE (in)
30	30 Tons 18" 11' 100"	34 Tons 12' 4' 10' 6.0 11.0 11.0 6.0	13.5	Single Axle: 18.00 x 24 96" Bogie Axle: 16.00 x 24	Single Axle: 14.00 x 20 32" 26" 96" Bogie Axle: 12.00 x 20	Single Axle: 14.00 x 20 x 96" Bogie Axle: 12.00 x 20	13,500 LBS on 18.00 x 24
40	40 Tons 22" 12' 112"	47 Tons 16' 4' 12' 14.0 13.0 13.0 7.0	17.0	Single Axle: 21.00 x 24 100" Bogie Axle: 18.00 x 24	Single Axle: 14.00 x 24 32" 32" 100" Bogie Axle: 14.00 x 20	Single Axle: 14.00 x 24 x 100" Bogie Axle: 14.00 x 20	17,000 LBS on 21.00 x 24
50	50 Tons 26" 13' 128"	58 Tons 16' 4' 12' 20.0 15.0 15.0 8.0	20.0	Single Axle: 24.00 x 29 112" Bogie Axle: 21.00 x 24	Single Axle: 16.00 x 24 37" 32" 112" Bogie Axle: 14.00 x 20	Single Axle: 16.00 x 24 x 112" Bogie Axle: 14.00 x 20	20,000 LBS on 24.00 x 29
60	60 Tons 28" 14' 132"	70 Tons 4' 15' 5' 12' 13.0 13.0 18.0 18.0 8.0	23.0		Single Axle: 18.00 x 24 41" 37" 128" Bogie Axle: 16.00 x 24	Single Axle: 18.00 x 24 x 128" Bogie Axle: 16.00 x 24	20,000 LBS on 24.00 x 29
70	70 Tons 31" 15' 138"	80.5 Tons 4' 15' 5' 12' 14.0 14.0 21.0 21.0 10.5	25.5		Single Axle: 18.00 x 24 41" 37" 132" Bogie Axle: 16.00 x 24	Single Axle: 18.00 x 24 x 132" Bogie Axle: 16.00 x 24	20,000 LBS on 24.00 x 29
80	80 Tons 33" 16' 144"	92 Tons 5' 18' 5' 12' 16.0 16.0 24.0 24.0 12.0	28.0		Single Axle: 21.00 x 24 49" 41" 138" Bogie Axle: 18.00 x 24	Single Axle: 21.00 x 24 x 138" Bogie Axle: 18.00 x 24	20,000 LBS on 24.00 x 29

Short Tons and Feet

N.B.:
(1) Single axle tire sizes shown in Columns 5,6, and 7 refer to the maximum single axle loads given in Column 4.
(2) Bogie axle tire sizes shown in Columns 5,6, and 7 refer to the maximum bogie axle loads shown on the diagram in Column 3.
(3) The maximum tire pressure for all tires shown in Column 8 shall be taken as 690 kN/m^2 (70 kp/cm^2, 100 lbs/in^2).
Actual contact pressures will depend on tire tread pattern and may be as high as 1100 kN/m^2 (112 kp/cm^2, 160 lbs/in^2).
(4) First value of tire size refers to nominal overall width of the tire and the second value refers to the rim diameter, both in inches.

APPENDIX C-2.3

HYPOTHETICAL VEHICLES FOR MILITARY LOAD CLASSES (US CUSTOMARY)

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	TRACKED VEHICLES	AXLE LOADS AND SPACING	MAXIMUM SINGLE AXLE LOAD	MINIMUM WHEEL SPACING AND TIRE SIZES (in) OF CRITICAL AXLES			MAX. TIRE LOAD AND MIN. TIRE SIZE (in)
90	90 Tons 35” 17’ 150”	103.5 Tons 5’ 18’ 5’ 12’ 18.0 18.0 27.0 27.0 13.5	30.0		Single Axle: 21.00 x 24 49” 41” 138” Bogie Axle: 18.00 x 24	Single Axle: 21.00 x 24 x 138” Bogie Axle: 18.00 x 24	20,000 LBS on 24.00 x 29
100	100 Tons 37” 18’ 156”	115 Tons 5’ 20’ 6’ 12’ 20.0 20.0 30.0 30.0 15.0	32.0		Single Axle: 21.00 x 24 49” 49” 144” Bogie Axle: 21.00 x 24	Single Axle: 21.00 x 24 x 144” Bogie Axle: 21.00 x 24	20,000 LBS on 24.00 x 29
120	120 Tons 40” 20’ 168”	138 Tonnes 5’ 20’ 6’ 12’ 24.0 24.0 36.0 36.0 18.0	36.0			x 154” Bogie Axle: 24.00 x 29	20,000 LBS on 24.00 x 29
150	150 Tons 50” 24’ 184”	170 Tonnes 6’ 22’ 7’ 12’ 32.0 32.0 42.0 42.0 22.0	42.0			x 160” Bogie Axle: 24.00 x 29	21,000 LBS on 24.00 x 29

Short Tons and Feet

N.B.:
(1) Single axle tire sizes shown in Columns 5,6, and 7 refer to the maximum single axle loads given in Column 4.
(2) Bogie axle tire sizes shown in Columns 5,6, and 7 refer to the maximum bogie axle loads shown on the diagram in Column 3.
(3) The maximum tire pressure for all tires shown in Column 8 shall be taken as 690 kN/m^2 (70 kp/cm^2, 100 lbs/in^2).
Actual contact pressures will depend on tire tread pattern and may be as high as 1100 kN/m^2 (112 kp/cm^2, 160 lbs/in^2).
(4) First value of tire size refers to nominal overall width of the tire and the second value refers to the rim diameter, both in inches.

APPENDIX D

INTERNATIONAL TEMPER EQUIVALENTS FOR ALUMINUM ALLOYS

Condition	UK	FRG (DIN 17007)	USA
As fabricated or manufactured	M	0	F
Annealed (wrought products only)	0	1	0
Strain hardened only	H1 to H8	2+3	H1 to H3
Annealed (cast products only)	TS	1	0
Solution heat-treated and naturally aged to substantially stable condition	TB	4+5	T1 to T4
Cooled from an elevated temperature shaping process and artificially aged	TE	--	T5
Solution heat-treated and then artificially aged	TF	6+7	T6
Solution heat-treated and stabilized/artificially overaged		9	T7
Solution heat-treated, cold worked, and artificially aged	TH	7	T8 T9 T10

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX E

COMPOSITE MATERIALS DATA FORM

Application:	**Designation of Supplier:**	**Country:** (Specify)

Cured Composite

Base Material:	Yes	No	Lay Up Geometry:
Woven fabric	O	O	No. of layers
Filament winding	O	O	Angles of layers
Pultrusions	O	O	Thickness of layers
Prepregs	O	O	Cured thickness
Cure Cycle:			Physical Properties:
			Density
Cured Composite Treatments:	Yes	No	Fiber volume content
Postcure	O	O	Void, volatile content
Thermal cycling	O	O	Moisture content
Mechanical cycling	O	O	Impact sensitivity
			Temperature range
			Test temperature
			Glass transition temperature

Basic Ply Lamina*

Mechanical Properties†:

Longitudinal tensile and compressive strength	X_T, X_C
Transverse tensile and compressive strength	Y_T, Y_C
In-plane shear strength	U_S
Longitudinal modulus	E_L
Transverse modulus	E_T
Shear modulus	G_S
Poisson's ratio	$v_L/E_L = v_T/E_T$
Longitudinal coefficient of thermal expansion	α_L
Transverse coefficient of thermal expansion	α_T

Resin	**Fiber**
Designation	Designation
Density	Density
Glass transition temperatures	Coefficient of thermal expansion
Coefficient of thermal expansion	Tensile Strength
Cure shrinkage	Longitudinal modulus
Tensile strength	Poisson’s ratio
Compressive strength	Tensile strain
Flexural strength	
Shear strength	
Tensile modulus	
Compressive modulus	
Shear modulus	

* Data should be reported at 23 °C (73 °F), 50% relative humidity (RH) and at 50 °C (122 °F), 85% RH and at higher or lower temperature if required.

† The temperature and humidity and preconditioning of specimens at which the data was obtained should be reported. Mean values and standard deviations should be reported for each mechanical property.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX F

ADHESIVE DATA FORM

Application: **Designation of System Components:** **Country:**

(Specify)

Availability: Yes No
- Liquid O O
- Paste O O
- Film O O

Cured mechanical properties:
- Tensile lap shear as function of test temperature and cure cycle and environmental exposure (temperature, humidity, duration)

Climbing drum peel and/or T-peel:
- (as a function of test temperature and cure cycle)

Cohesive tensile strength:

Stress rupture environmental test:

Compression modulus

Shear modulus

Elastic and non-elastic shear strain limits

Wedge crack propagation in agreed environment

Physical properties:
- Density
- Volatiles
- Glass transition temperature
- Electric transverse resistivity
- Saturation moisture content
- Swelling coefficient

Cure cycle:
- (temperature, duration, pressure)

Primer designation:

Setting agent designation:

Allowable bond thickness:

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX G

TYPICAL BASIC PROPERTIES* OF FIBER-REINFORCED MATERIALS BASED ON 60% FIBER VOLUME FRACTION EPOXY COMPOSITES (Not to be used for design)

Material and Fiber Orientation	Density (kg/m^3)	Ultimate Tensile Strength (N/mm^2)	Ultimate Compressive Strength (N/mm^2)	Ultimate Inplane Shear Strength (N/mm^2)	Young's Modulus (kN/mm^2)
Unidirectional Composites, 0°					
Carbon fiber high modulus	1550	900	750	70	200
Carbon fiber medium modulus	1540	1500	925	70	130
Carbon fiber high tensile strength	1540	1430	840	70	110
E glass	2100	1340	760	70	42
Kevlar 19	1400	1430	290	70	80
Bidirectional Composites, 0°/90°					
Carbon fiber high modulus	1550	450	380	140	100
Carbon fiber medium modulus	1540	760	460	140	65
Carbon fiber high tensile strength	1540	670	420	160	58
E glass	2100	670	525	140	25
Kevlar 19	1400	670	210	109	42
Pseudo Isotropic Composites, 0±60°					
Carbon fiber high modulus	1550	300	420	294	63
Carbon fiber medium modulus	1540	504	504	294	46
Carbon fiber high tensile strength	1540	504	504	336	40
E glass	2100	400	420	302	18
Kevlar 19	1400	504	168	168	27

* Properties at 20 °C (68 °F) with preferred manufacturing methods (pultrusions, prepregs, filament winding).

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX H

SAFETY FACTORS ON REQUIRED LIFE *n* FOR DESIGN AND TEST

Type of Design	DESIGN Related to Min S/N Curve (97.5%)	 Related to Mean S/N Curve (50%)	TEST
Fail safe damage tolerant	1.5	1.5 x 1.5 = 2.25	1.0 x Table*
Safe life monitored usage	1.5 x 1.5 = 2.25	1.5 x 2.25 = 3.37	1.5 x Table*
Safe life unmonitored usage	1.5 x 10 = 15	2.25 x 10 = 22.5	10 x Table*
Safe life unmonitored, unchanged load spectrum	1.5 x 6.7 = 10	2.25 x 6.7 = 15.75	6.7 x Table*
Infinite life	1.33†	1.33† x 1.5 = 2	

* See values from table given in paragraph 8.8.4.

† The value 1.33 is taken as that at $n = 1x10^7$ cycles for steels or $2x10^6$ cycles for aluminum alloys.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX I

LIMIT STATE DESIGN (LSD) (Provisional)

I.1 Static Design In order to achieve a more uniform degree of safety, taking account of the variance of loads and structural resistance, Limit State Design may be employed. Under this procedure, both an Overload Check (paragraph I.4) and an Ultimate Check (paragraph I.5) will be satisfied.

Structures designed in accordance with this Appendix are still required to satisfy the practical Overload Test, as specified in paragraph 8.5.10.

I.2 Loading Two levels of loading on the structure are considered, namely the Design Load, *P*, and the Overload, *O*. These are defined as follows:

P = loading derived in accordance with paragraph 6.2, Design Load, *P*, by taking an appropriate combination of dead and applied loads in order of decreasing severity.

O = loading derived generally as for P, but with the introduction of a further factor γ_f.

The factor γ_f required for determining the Overload, *O*, is applied to any given load in addition to the order-of-severity factor. Its value, which varies according to the nature of the individual load being considered, is taken from Table I.1. Thus, for dead load, *D*, the contribution to the Overload would be 1.2*D*; while for an imposed load constituting the second most severe applied load, A_2, the contribution would be 1.33A_2.

Table I.1 Partial load factor γ_f

Load		γ_f
Dead Load:	Direct effect	1.2
	Countering uplift	0.8
Imposed Load (excluding wind)		1.33
Wind Load		1.20
Temperature Effect		1.00

I.3 Actions By "Action" is meant the axial load, bending moment, shear force or torque acting at a cross-section of a member or on the member as a whole. It also refers to the force or couple transmitted by a joint.

Two levels of action (*PA*, *OA*) are considered, defined as follows:

PA = action arising from the application of the Design Loading, *P*, to the structure.

OA = action arising from the application of the Overload, O, to the structure.

I.4 Overload Checks

I.4.1 Basic requirement. The following will be satisfied for any component (member, joint):

$$OA \leq \frac{R_1}{\gamma_{m1}}$$

where: OA = action arising when the Overload, O, is applied to the structure (see paragraph I.3, Actions)

R_1 = resistance of the member or joint based on initial yield

γ_{m1} = factor depending on the form of construction, from Table I.2.

Table I.2 Partial Load Factors γ_{m1} and γ_{m2}

Construction Form		γ_{m1}	γ_{m2}
Members:	Unwelded	1.00	1.10
	Welded	1.05	1.15
Joints:	Bolted or Riveted	1.05	1.15
	Welded	1.10	1.20

I.4.2 Resistance *R*₁. This is the ability to withstand the action considered, which by elastic analysis would just cause a stress to be developed equal to the appropriate value in Table I.3. In this table, f_O is the minimum specified 0.2% proof stress or yield stress of the material.

Local stress concentrations may be ignored in the determination of R_1, provided they can be absorbed by the ductility of the material.

Table I.3 Limiting Elastic Stresses for Use in Overload Check

Stress	Factor
Direct stress due to axial load	f_O
Direct stress due to bending moment	$1.10f_O$
Shear stress	$0.60f_O$
Bearing stress	$1.33f_O$

I.4.3 Welded members. In applying the Overload Check to welded members or joints, a suitable allowance will be made for Heat Affected Zone (HAZ) softening adjacent to welds, when necessary. In so doing, it is permissible to take an effective section when performing the elastic stress analysis required for the determination of R_1.

It is generally permissible, at a partially welded cross-section, for the stress in the HAZ to exceed the relevant Table I.3 value based on HAZ material properties. But, this does not apply to the design of connections.

I.5 Ultimate Checks

I.5.1 Basic requirement. The following will be satisfied for any member or joint:

$$OA \leq \frac{R_2}{\gamma_{m2}}$$

where: OA = action arising when the Overload, O, is applied to the structure (see paragraph I.3, Actions).

R_2 = calculated ultimate resistance of the member or joint.

γ_{m2} = factor depending on the form of construction, from Table I.2 .

I.5.2 Resistance R_2. This is the ability to just withstand the action considered without failure in any of the following ways:

(a) Local cracking or rupture.
(b) Failure by buckling.
(c) Plastic deformation sufficient to make the member or joint unfit for use, such as
  (i) Formation of a plastic hinge in a beam.
  (ii) Yielding of a shear web over its full depth.
  (iii) Yielding across the section of an axially loaded member.

In the determination of R_2 it should be assumed that:

(a) the metal has minimum specification properties, and
(b) the fabrication procedures produce a severity of defect or imperfection that is deemed to be just acceptable.

I.6 Combined Actions When a component is subjected to two or more different actions simultaneously, its acceptability will be assessed using suitable interaction formulas. This applies to both the Overload and Ultimate checks.

I.7 Reliability Approach Annex 1 gives a probabilistic procedure for the determination of the factors γ_f and γ_{m2} which may be employed instead of Tables I.1 and I.2. The factor γ_{ml} should remain unchanged.

APPENDIX I: ANNEX 1

DETERMINATION OF PARTIAL LOAD FACTORS

I.A1.1 Paragraph I.7, Reliability Approach, permits partial load factors γ_{m2} and γ_f to be determined if sufficient data is available. This Annex sets out how it is to be done.

I.A1.2 In this Annex the following additional symbols are used:

M = Mean

V = Coefficient of variance

x = Parameter determining resistance X

X = Calculated resistance to actions Y (also used as suffix)

Y = Action from design load (also used as suffix)

μ = Safety index representing a reliability level

β = Safety index representing a reliability level

γ_{m2} = Partial load factor associated with x (the material resistance)

γ_f = Partial load factor associated with Y (the force or other action)

σ = Standard deviation

I.A1.3 The following steps are used in determining the partial load factors:

Step 1 - Specification of the intended reliability level.

Step 2 - Determination of V_x and V_y.

Step 3 - Calculation of partial load factors γ_{m2} and γ_f.

I.A1.4 It is assumed that the design equation is of the type:

$$\frac{X}{\gamma_{m2}} \geq \gamma_f Y$$

with X the characteristic value (2.5% fractile) of the structural resistance and Y the characteristic value (97.5% fractile) of the loading.

I.A1.5 **<u>Step 1:</u>** These figures are used:

β_S = 3.2, failure mode affecting serviceability

β_L = 4.7, failure mode affecting load carrying capacity

In the case of redundancy, or components not essential for load carrying capability, β can be reduced by 0.5.

I.A1.6 **<u>Step 2:</u>** These equations are used:

$$V_x = \frac{\sigma_x}{M_x} \text{ and } V_y = \frac{\sigma_y}{M_y}$$

These values are obtained by applying the square root formula and by inputting individual mean values. For example, if the resistance is determined by a set or parameters, $x_1, x_2, \ldots x_n$, then:

X = $f(x_1, x_2, \ldots x_n)$,

M = $f(m_1, m_2, \ldots m_n)$, and

$$x = \sqrt{\sum \left(\frac{\partial f}{\partial x_1} \sigma_1^2 \right)}$$

I.A1.7 **<u>Step 3:</u>** For normally distributed resistance and loading, the partial load factors are obtained from:

$$\gamma_{m2} = \frac{1 - 1.96V_x}{1 - \alpha_x \beta V_x} \text{ and } \gamma_f = \frac{1 - \alpha_y \beta V_y}{1 + 1.96V_y}$$

with: if $\beta_S \leq 3.2$, then $\alpha_x = 0.75$, $\alpha_y = -0.75$
if $\beta_L \leq 4.7$, then $\alpha_x = 0.9$, $\alpha_y = -0.65$

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX J

STANDARDS

The following list of Standards is related to the paragraphs of this Code.

Paragraph	Standard(s)	
3.5.3.1	ASTM E8	- Tension Testing of Metallic Materials ISO/R82, R86, R375, BS 18
3.5.3.2	ASTM E9	- Compression Testing of Metallic Materials at Room Temperature
3.5.3.3	ASTM E238	- Pin - Type Bearing Test of Metallic Materials
3.5.3.4	ASTM B565	- Shear Testing of Aluminum and Aluminum-Alloy Rivets and Cold-Heading Wire and Rods
3.5.5	ASTM E399	- Plane Strain Fracture Toughness of Metallic Materials, Test for
3.6.1	ASTM D618	- Conditioning Plastics and Electrical Insulating Materials for Testing
	ASTM D3039	- Tensile Properties of Fiber-Resin Composites, Test for
	ASTM D3410	- Compressive Properties of Unidirectional or Crossply Fiber-Resin Composites, Test for
	ASTM D3518	- In-Plane Stress-Strain Response of Unidirectional Reinforced Plastics
3.6.4.1	ASTM D3171	- Fiber Content of Resin-Matrix Composites by Matrix-Digestion, Test for
	ASTM D792	- Specific Gravity (Relative Density) and Density of Plastics by Displacement, Test for
3.6.5	ASTM D3039	- Tensile Properties of Oriented Fiber-Resin Composites, Test for
	ASTM D3410	- Compressive Properties of Unidirectional or Crossply Fiber-Resin Composites, Test for
	ASTM D3518	- In-Plane Stress-Strain Response to Unidirectional Reinforced Plastics
3.6.6	ASTM D3039	- Tensile Properties of Fiber-Resin Composites, Test for
	ASTM D3479	- Tension - Tension Fatigue of Oriented Fiber, Resin Matrix Composites, Test for

Paragraph	Standard(s)
3.6.8	ASTM D3039 - Tensile Properties of Fiber-Resin Composites, Test for
3.7.5	ASTM E229 - Shear Strength and Shear Modulus of Structural Adhesives, Test for
	ASTM D1876 - Peel Resistance of Adhesives (T-Peel Test), Test for
	ASTM D897 - Tensile Properties of Adhesive Bonds, Test for
	ASTM D3167 - Floating Roller Peel Resistance of Adhesives, Test for
3.7.6	ASTM D3166 - Fatigue Properties of Adhesives in Shear by Tension Loading (Metal/Metal), Test for
3.7.8	ASTM D2294 - Creep Properties of Adhesive in Shear by Tension Loading (Metal/Metal), Test for,
	BS3250 Part C7
4.2.1	STANAG 2021- Computation of Bridge, Ferry, Raft, and Vehicle Classifications
5.3.2.1	STANAG 2021- Computation of Bridge, Ferry, Raft, and Vehicle Classifications
11.1	DOD Directive 5000.40 - Reliability and Maintainability
	MIL-STD-785B - Reliability Program for Systems and Equipment, Development and Production
	MIL-STD-721C - Definitions of Terms for Reliability and Maintainability